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AERODYNAMIC CHARACTERISTICS AT MACH NUMBERS FROM 1.50 TO 4.63 OF A MANEUVERABLE MISSILE WITH IN-LINE CRUCIFORM WINGS AND CANARD SURFACES

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SUMMARY

An investigation has been conducted in the Langley Unitary Plan wind tunnel at Mach numbers from 1.50 to 4.63 to determine the aerodynamic characteristics of a maneuverable missile having in-line cruciform wings and canard surfaces oriented in 45° roll planes. The results indicated satisfactory longitudinal and directional stability characteristics throughout the angle-of-attack and Mach number range. Deflection of the canard controls provided a high degree of longitudinal maneuverability throughout the Mach number range. Deflection of wing trailing-edge flaps provided effective roll control with essentially no induced yawing moments. Deflection of the canard controls provided effective directional control but also induced significant adverse rolling moments.

INTRODUCTION

The National Aeronautics and Space Administration has conducted an investigation to determine the static aerodynamic characteristics of a model which simulated a maneuverable missile configuration. The model had cruciform wings and in-line cruciform canard surfaces. The wings in one plane were equipped with trailing-edge flaps and the canard surfaces in both planes were all-movable. Previous tests of the model have been made (see ref. 1) wherein the wing and canard surfaces were oriented in the horizontal and vertical planes with respect to the plane of the angle of attack (roll angle ϕ of 0°). For the results presented herein, the wing and canard surfaces were in 45° planes with respect to the plane of angle of attack ($\phi = 45^{\circ}$).

The investigation was performed in the Langley Unitary Plan wind tunnel at Mach numbers from 1.50 to 4.63 at a constant Reynolds number per foot of 2.5×10^{6}. The angle of attack was varied from about -4° to 30° for angles of sideslip of 0° and about 2°.

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*[redacted]

SYMBOLS

The aerodynamic-coefficient data are referred to the body-axis system except for lift and drag which are referred to the stability-axis system. The moment reference was located at 60.2 percent of the body length aft of the model nose.

A	maximum cross-sectional area of body, 0.068849 sq ft (0.0064 m^2)
d	reference diameter (maximum cross section), 3.54 in. (8.99 cm)
C_A	axial-force coefficient, $\frac{\text{Axial force}}{qA}$
C_D	drag coefficient, $\frac{\text{Drag}}{qA}$
$C_{A,b}$	base axial-force coefficient
$C_{D,o}$	drag coefficient at $\alpha = 0^{\circ}$
C_L	lift coefficient, $\frac{\text{Lift}}{qA}$
C_l	rolling-moment coefficient, $\frac{\text{Rolling moment}}{qAd}$
C_{l_β}	rolling-moment parameter, $\frac{\Delta C_l}{\Delta \beta}$
C_{l_δ}	roll-control effectiveness, $\frac{C_l}{\delta_{roll}}$
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qAd}$
C_{m_δ}	pitch-control effectiveness, $\frac{C_m}{\delta_{pitch}}$
C_N	normal-force coefficient, $\frac{\text{Normal force}}{qA}$

[redacted]

C_{L_α} slope of lift curve measured near zero α

C_n yawing-moment coefficient, $\frac{\text{Yawing moment}}{qAd}$

C_{n_β} directional stability parameter, $\frac{\Delta C_n}{\Delta \beta}$

C_{n_δ} yaw-control effectiveness, $\frac{C_n}{\delta_{yaw}}$

C_Y side-force coefficient, $\frac{\text{Side force}}{qA}$

C_{Y_β} side-force parameter, $\frac{\Delta C_Y}{\Delta \beta}$

L/D lift-drag ratio

M Mach number

q dynamic pressure

α angle of attack, deg

β angle of sideslip, deg

δ_{pitch} deflection of canard surfaces to provide pitching moment, deg

δ_{yaw} deflection of canard surfaces to provide yawing moment, deg

δ_{roll} differential wing flap deflection to provide rolling moment, deg

ϕ angle of wing chord plane with respect to lateral reference plane, deg

x_{ac}/l location of aerodynamic center referred to body length

x_{cg}/l location of center of gravity referred to body length

APPARATUS AND TESTS

Tunnels

The investigation was conducted in the Langley Unitary Plan wind tunnel which is a variable-pressure continuous-flow facility. The tunnel has two 4-foot-square test sections and the nozzles leading to the test sections are of the asymmetric sliding-block type which permit a continuous variation in test-section Mach number from 1.5 to 2.9 in the low Mach number test section and from 2.3 to 4.7 in the high Mach number test section.

Model

Dimensional details of the model oriented at $\phi = 0^{\circ}$ are shown in figure 1, and the model mounted in the test section is shown in figure 2. The body had a fineness ratio of about 11.3. The cruciform trapezoidal wings had beveled leading and trailing edges with a maximum thickness ratio of 4 percent. Both wings in one plane were equipped with trailing-edge flaps having an overhang balance. The all-movable cruciform trapezoidal canard surfaces also had beveled leading and trailing edges with a thickness ratio of 4 percent and were in line with the wings. The model was also provided with protuberances which simulated equipment fairings.

Tests

The conditions under which the tests were conducted are as follows:

Mach number	Stagnation pressure		Stagnation temperature	
	lb/sq ft abs	kN/m^2	$^{\circ}$F	$^{\circ}$K
1.50	1390	66.55320	150	338.705217
1.90	1585	75.88980	150	338.705217
2.30	1910	91.45080	150	338.705217
2.96	2700	129.27600	150	338.705217
3.95	4800	229.82400	175	352.594092
4.63	6575	314.81100	175	352.594092

The Reynolds number was 2.5×10^6 per foot (per 0.3048 meter). The dewpoint, measured at stagnation pressure, was maintained low enough to assure negligible condensation effects. The angle of attack was varied from approximately -4° to 30° at angles of sideslip of 0° and about 2°. In order to assure boundary-layer transition to turbulent conditions, 1/16-inch-wide (0.15 cm) strips of No. 60 carborundum grit were placed 0.4 inch (1.016 cm) from the leading edge of the wings and at 15-percent chord on the canards, measured streamwise, and on the body 1.6 inches (4.064 cm) from the nose tip.

Measurements

Aerodynamic forces and moments on the model were measured by means of a six-component electrical strain-gage balance which was housed within the model. The balance was attached to a sting which, in turn, was rigidly fastened to the tunnel support system. Balance-chamber pressure was measured by means of a single static-pressure orifice located in the vicinity of the balance.

Corrections and Accuracy

The angles of attack and sideslip have been corrected for deflection of the balance and sting due to aerodynamic loads; angles of attack have also been corrected for tunnel airflow misalinement. The drag and axial-force coefficients have been adjusted to correspond to free-stream static pressure acting over the model base. (See fig. 3.)

Based on balance calibration and data repeatability, the data presented herein are estimated to be accurate to within the following limits:

C_A, C_D	±0.015
$C_{A,b}$	±0.005
C_N, C_L	±0.076
C_m	±0.057
C_n	±0.029
C_l	±0.010
C_Y	±0.029
M (1.50, 1.90, 2.30, and 2.96)	±0.015
M (3.95 and 4.63)	±0.050
α, deg	±0.1
β, deg	±0.1

PRESENTATION OF RESULTS

The results of the investigation are presented in the following figures:

DISCUSSION

Longitudinal Characteristics

Deflection of the four canard surfaces provides effective pitch control throughout the angle-of-attack and Mach number range with little effect on the lift but with a measurable increase in drag. (See fig. 4.) The pitching-moment increments provided by canard deflection progressively decrease with increasing angle of attack at the lower Mach numbers. (See fig. 4(a).) At the higher Mach numbers, however, the effectiveness of the canard surfaces initially increases with increasing angle of attack and then decreases. (See fig. 4(f).) The results presented in reference 1 for the configuration at $\phi = 0^{\circ}$ indicated a progressive increase in control effectiveness at the higher Mach numbers throughout the angle-of-attack range. The decrease in effectiveness at the higher angles of attack for the present configuration ($\phi = 45^{\circ}$) indicates a possible interference effect of the windward canard surfaces on the leeward canard surfaces.

In general, the variations of pitching moment with angle of attack for the complete model are reasonably linear, and at the higher angles of attack and Mach number (fig. 4(f), for example), exhibit a significant pitch-down tendency.

A summary of some of the longitudinal aerodynamic parameters at $\alpha = 0^{\circ}$ is shown in figure 5. The pitch effectiveness $C_{m_{\delta}}$ is slightly greater than that indicated for the configuration at $\phi = 0^{\circ}$ (ref. 1) whereas there is essentially no difference in the values of x_{ac}/l, $C_{L_{\alpha}}$, and $C_{D,o}$ obtained at $\phi = 45^{\circ}$ and $\phi = 0^{\circ}$ (ref. 1). The variation of the aerodynamic-center location indicates a slight forward movement with increasing Mach number which should provide a compatible relationship with the center-of-gravity movement to be expected with fuel consumption.

A summary of the longitudinal maneuvering characteristics is presented in figure 6 for the configuration at $\phi = 0^{\circ}$ (ref. 1) and at $\phi = 45^{\circ}$ (present results). These results represent the maximum trim values of C_L obtainable with canard surfaces deflected 20° for various positions of the center of gravity. These results are limited only to statically stable conditions and are terminated at the Mach number or aft center-of-gravity position for which more than one trim point occurs. The results indicate that fairly high values of trim C_L are available particularly at the higher Mach numbers. The configuration at $\phi = 45^{\circ}$ is less sensitive to center-of-gravity position than at $\phi = 0^{\circ}$ and indicates generally higher maneuvering limits over the Mach number range.

Sideslip Derivatives

The sideslip derivatives (fig. 7) indicate generally satisfactory directional stability for the complete configuration throughout the angle-of-attack and Mach number range. Deflection of all four canard surfaces for pitch control has a measurable effect on the directional stability characteristics of the complete configuration that is generally favorable at the lower Mach numbers (fig. 7(b), for example) but becomes adverse at the higher Mach numbers (fig. 7(f)). Deflection of the canards for pitch control also causes a generally negative increment in rolling moment due to sideslip at all Mach numbers. An induced roll is indicated, particularly at the lower Mach numbers, by the rapid increase in $-C_{l_\beta}$ with increasing angle of attack even for zero control deflection. (See fig. 7(a).) An indication of the influence of roll attitude on the induced-roll characteristics may be noted by the fact that the configuration at $\phi = 0^{\circ}$ (ref. 1) indicates a rapid increase in $+C_{l_\beta}$ with increasing angle of attack that is opposite in direction to that which occurs at $\phi = 45^{\circ}$.

Lateral Control

Differential deflection of the two wing flaps (with canard surfaces undeflected) provides an effective means of obtaining roll control with little or no induced yawing moment throughout the angle-of-attack and Mach number range. (See fig. 8.) With increasing Mach number, the roll effectiveness of the flaps decreases at low angle of attack; however, the effectiveness increases substantially with increasing angle of attack at the higher Mach numbers.

Deflection of the four canard surfaces (with wing flaps undeflected) provides an effective means of obtaining yaw control throughout the angle-of-attack and Mach number range. (See fig. 9.) However, deflection of the canards also produces a flow field at the wing that induces some adverse rolling moment. In fact, in some instances the induced roll caused by a 20° canard deflection is in excess of the rolling moment that could be controlled by a wing flap deflection of ±20°. (Compare figs. 9(b) and 8(b) at $\alpha = 10^{\circ}$, for example.)

The variation of roll-control effectiveness and yaw-control effectiveness with Mach number at $\alpha = 0^{\circ}$ is presented in figure 10. Results for $\phi = 0^{\circ}$ obtained from reference 1 are included.

CONCLUDING REMARKS

An investigation has been conducted in the Langley Unitary Plan wind tunnel at Mach numbers from 1.50 to 4.63 to determine the aerodynamic characteristics of a maneuverable missile having in-line cruciform wings and canard surfaces oriented in 45° planes.

The results indicated satisfactory longitudinal and directional stability characteristics throughout the angle-of-attack and Mach number range. Deflection of the canard controls provided a high degree of longitudinal maneuverability throughout the Mach number range. Deflection of wing trailing-edge flaps provided effective roll control with essentially no induced yawing moments. Deflection of the canard controls provided effective yaw control but also induced significant adverse rolling moments.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., November 8, 1966,
126-13-02-01-23.

REFERENCE

1. Corlett, William A.: Aerodynamic Characteristics of a Maneuverable Missile With Cruciform Wings and In-Line Canard Surfaces at Mach Numbers From 0.50 to 4.63. NASA TM X-1309, 1966.

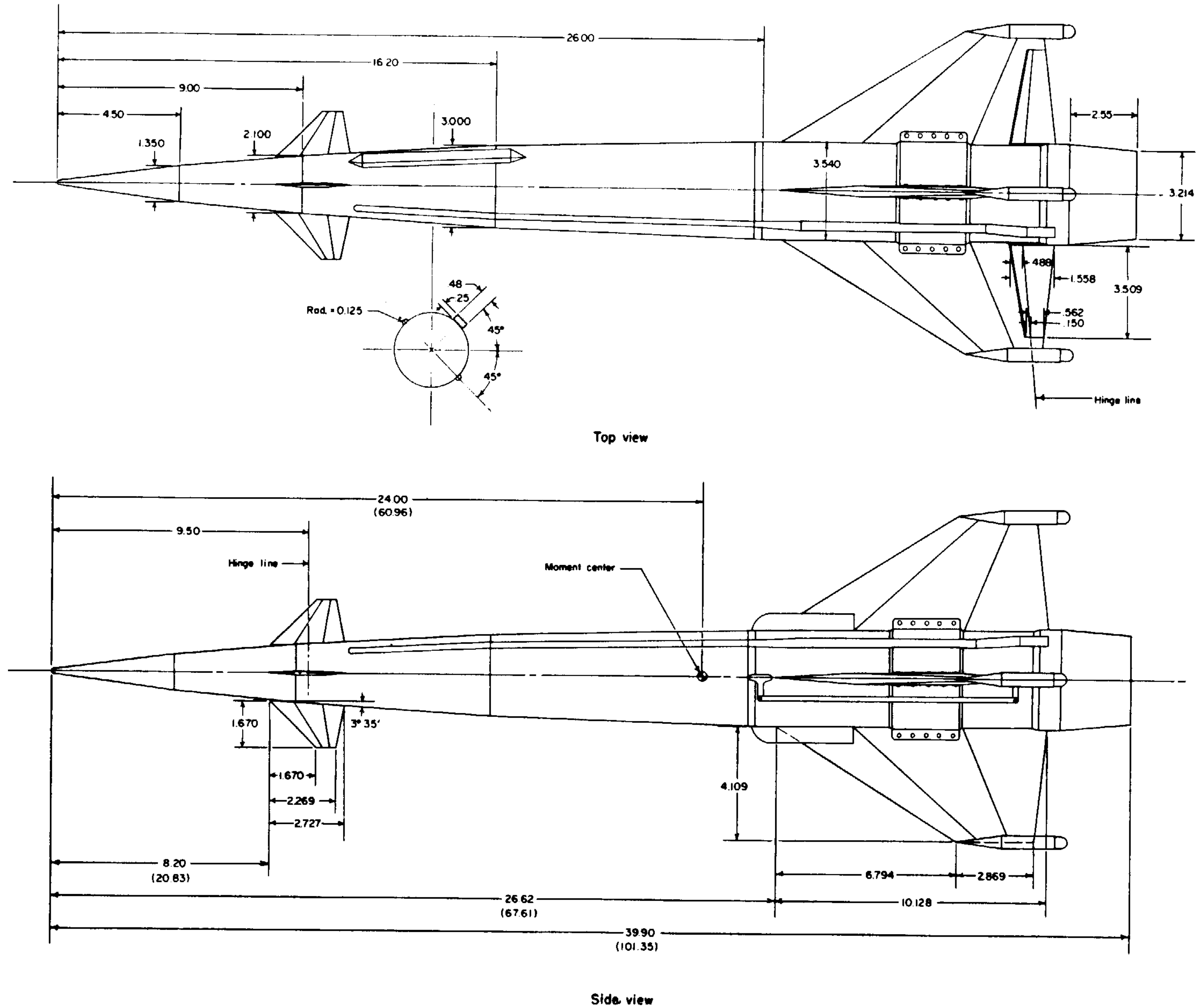


Figure 1.- Model shown with surfaces oriented in 0° roll plane.

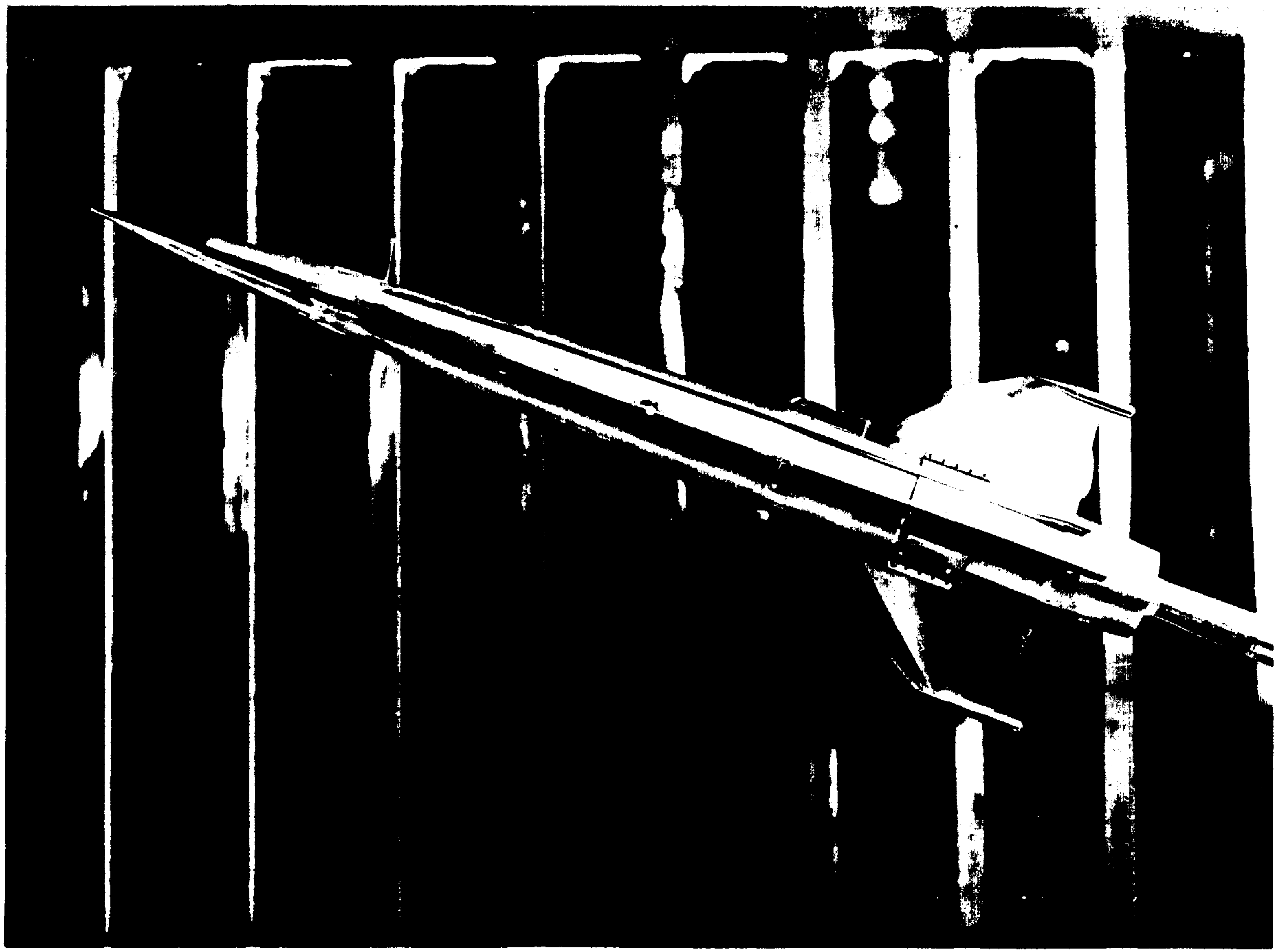


Figure 2.- Model mounted in Langley Unitary Plan wind tunnel. $\Phi = 0^{\circ}$ (ref. 1). L-65-2685

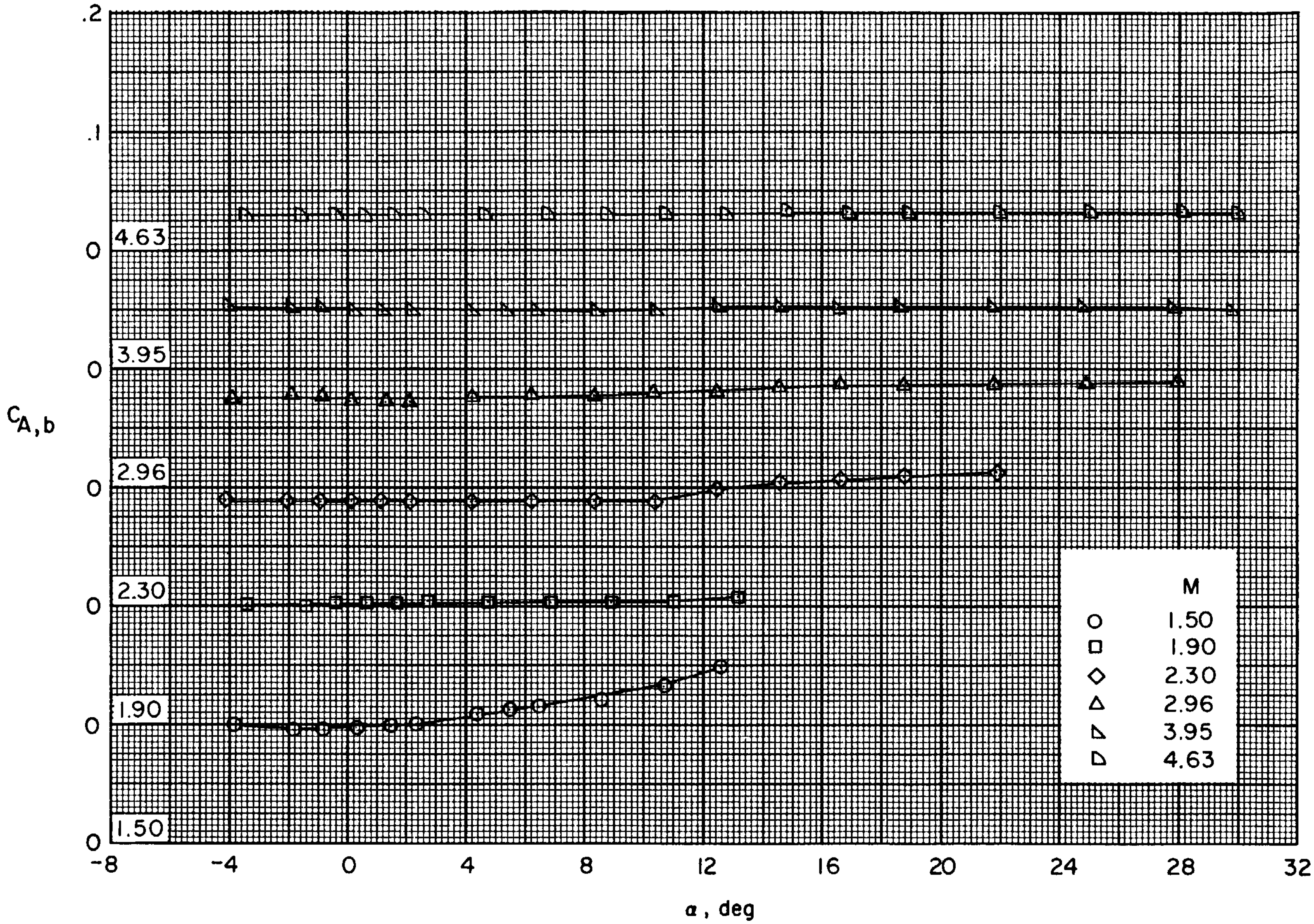
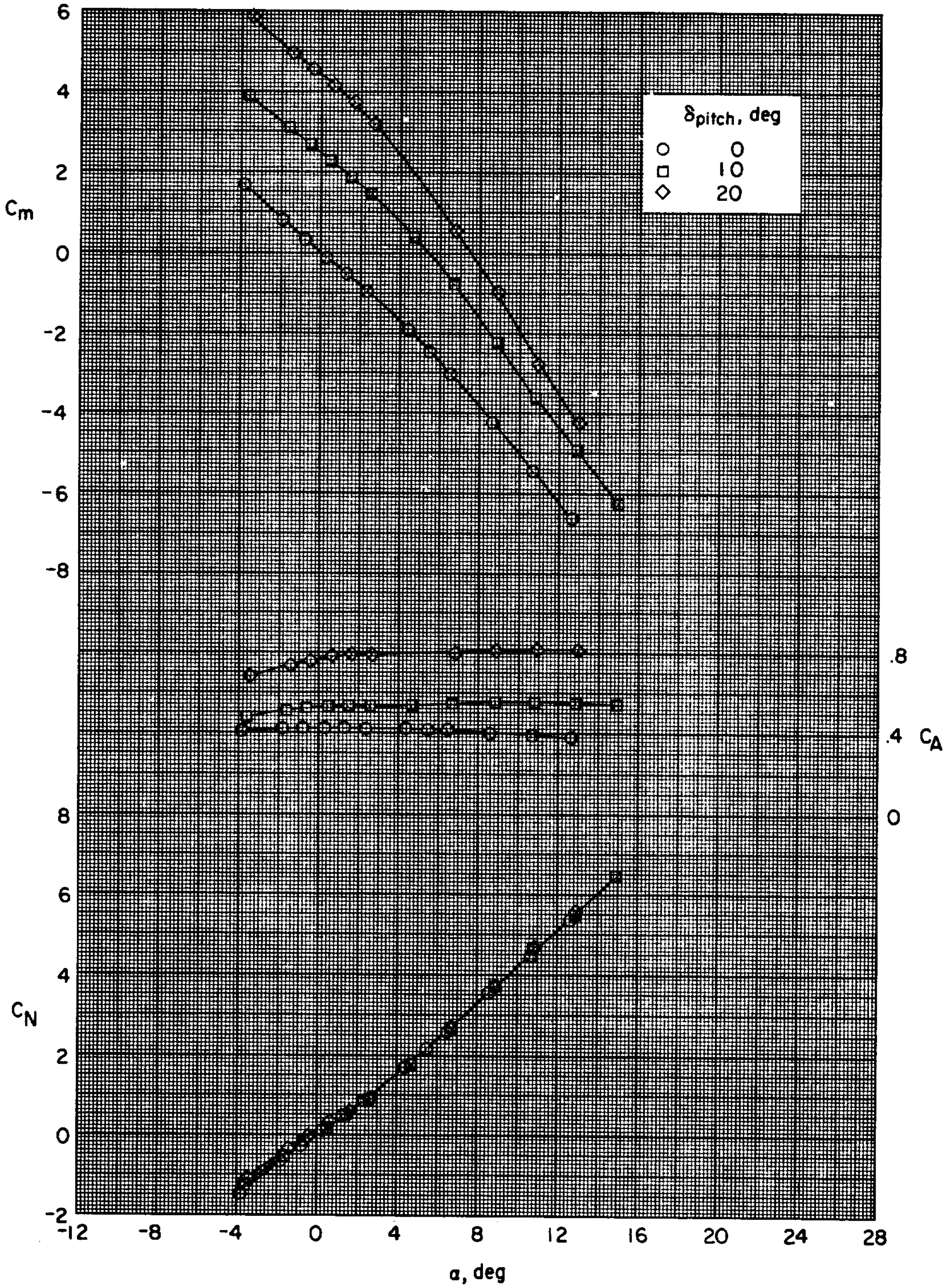
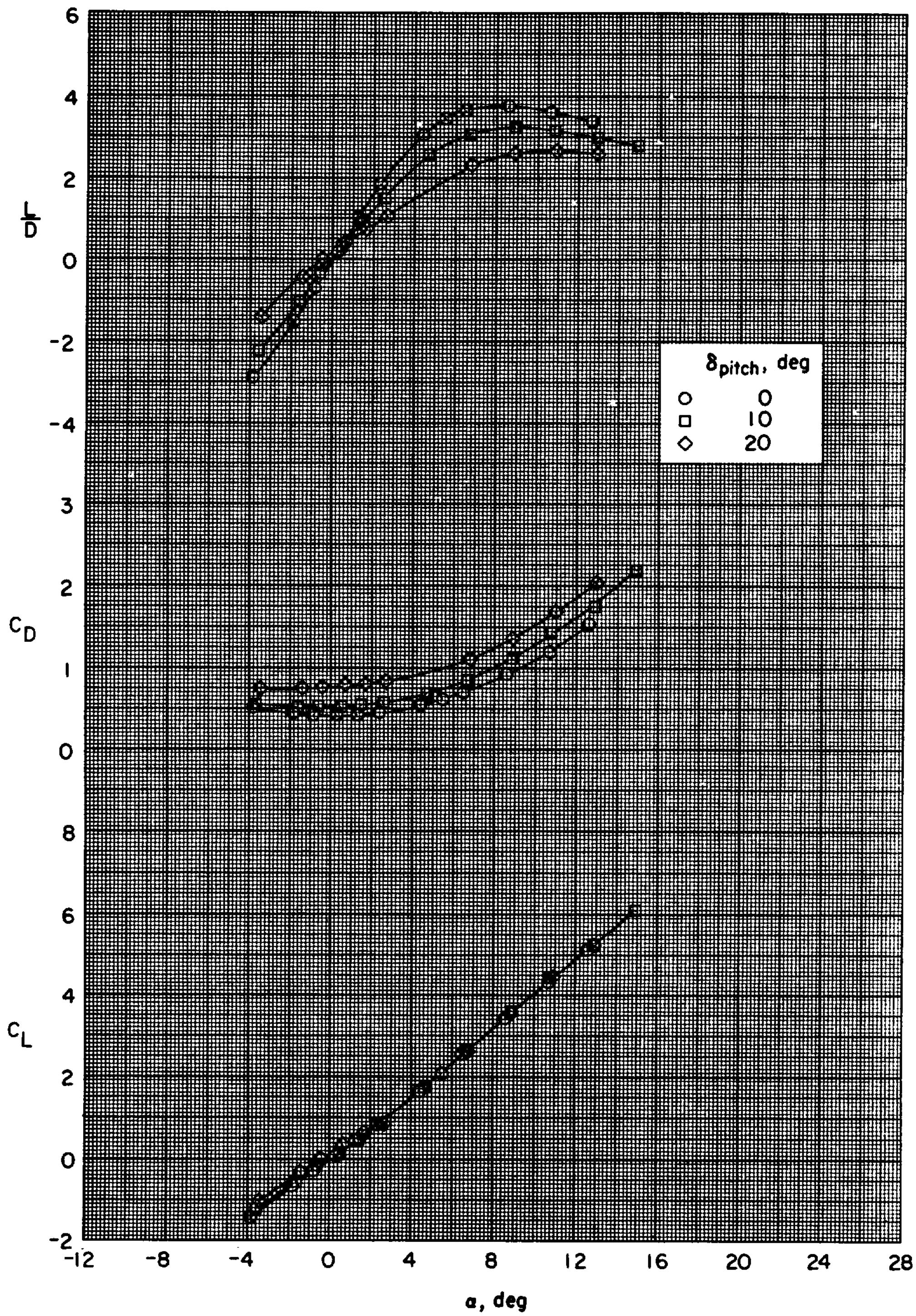


Figure 3.- Variation of base axial-force coefficient with angle of attack.



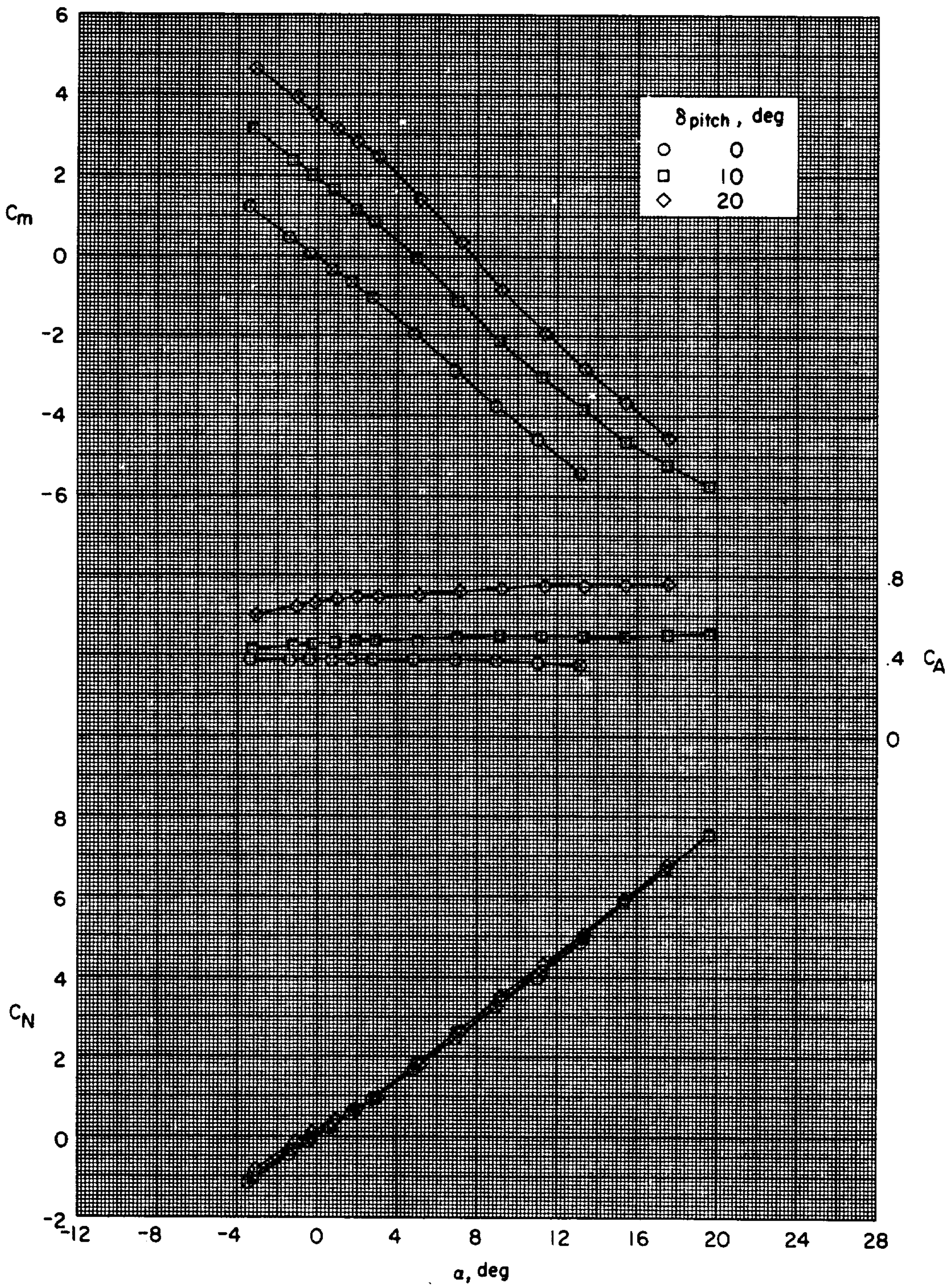
(a) M = 1.50.

Figure 4.- Effect of canard pitch-control deflection on the longitudinal aerodynamic characteristics.



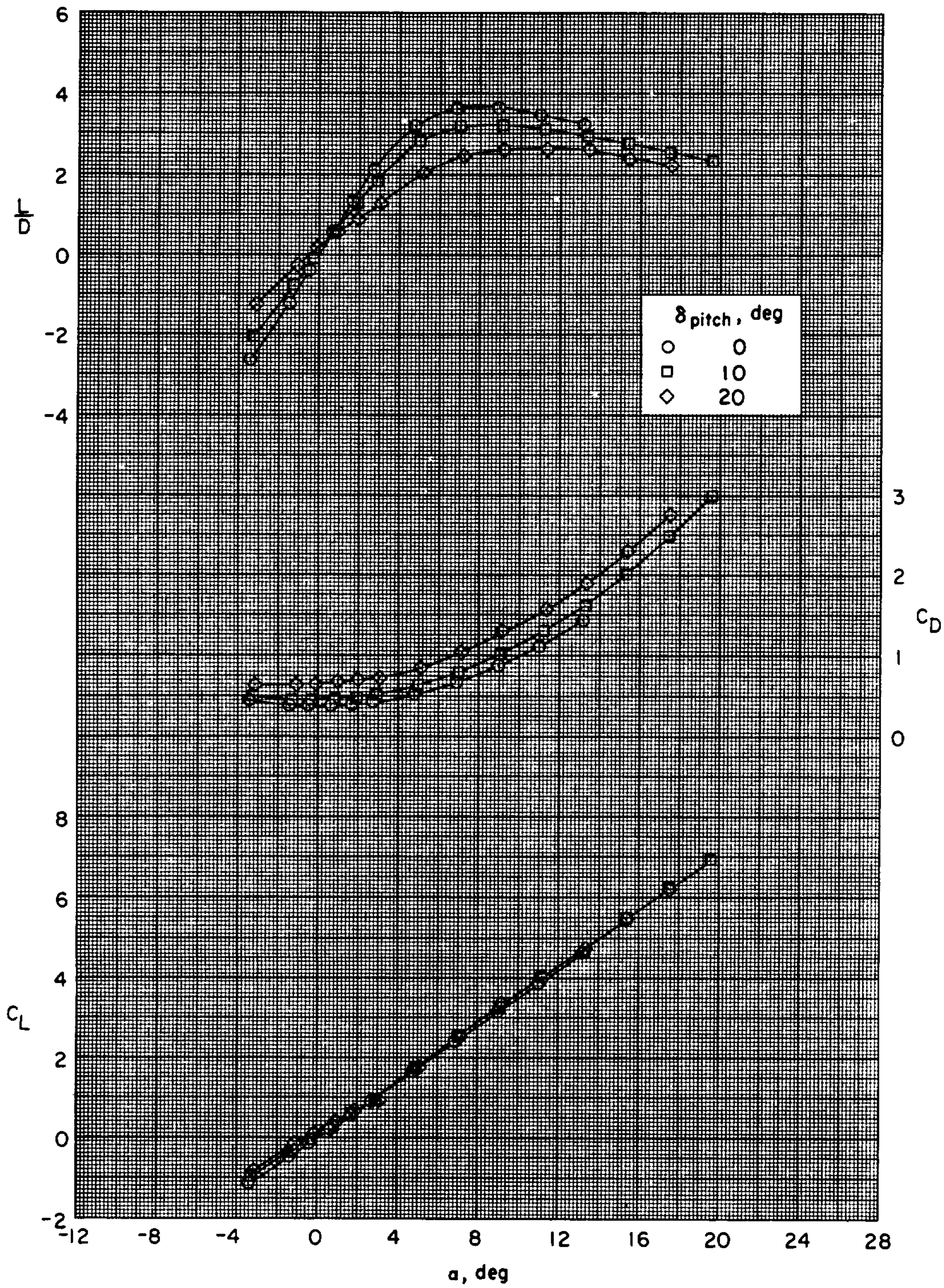
(a) Concluded.

Figure 4.- Continued.



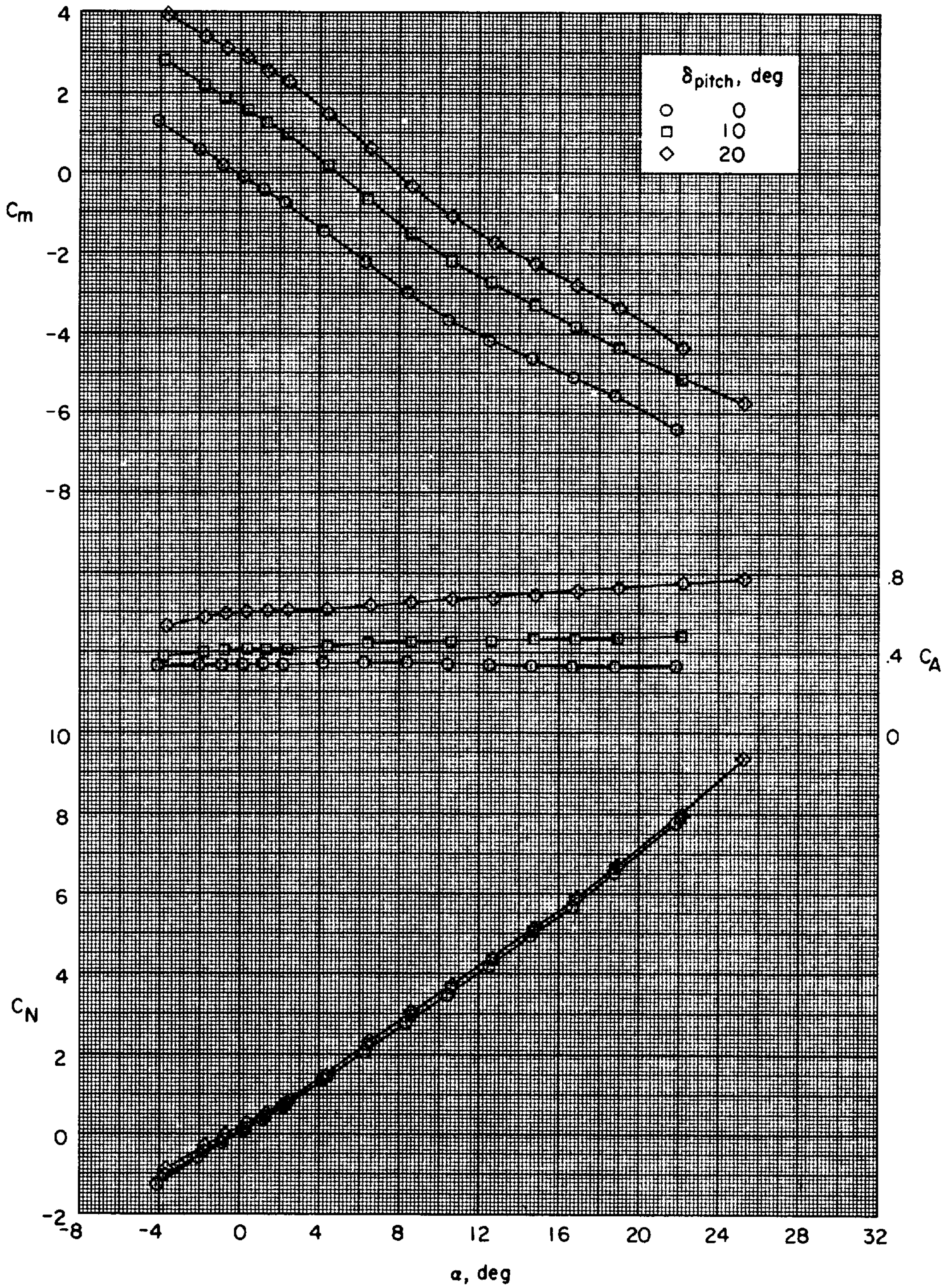
(b) M = 1.90.

Figure 4.- Continued.



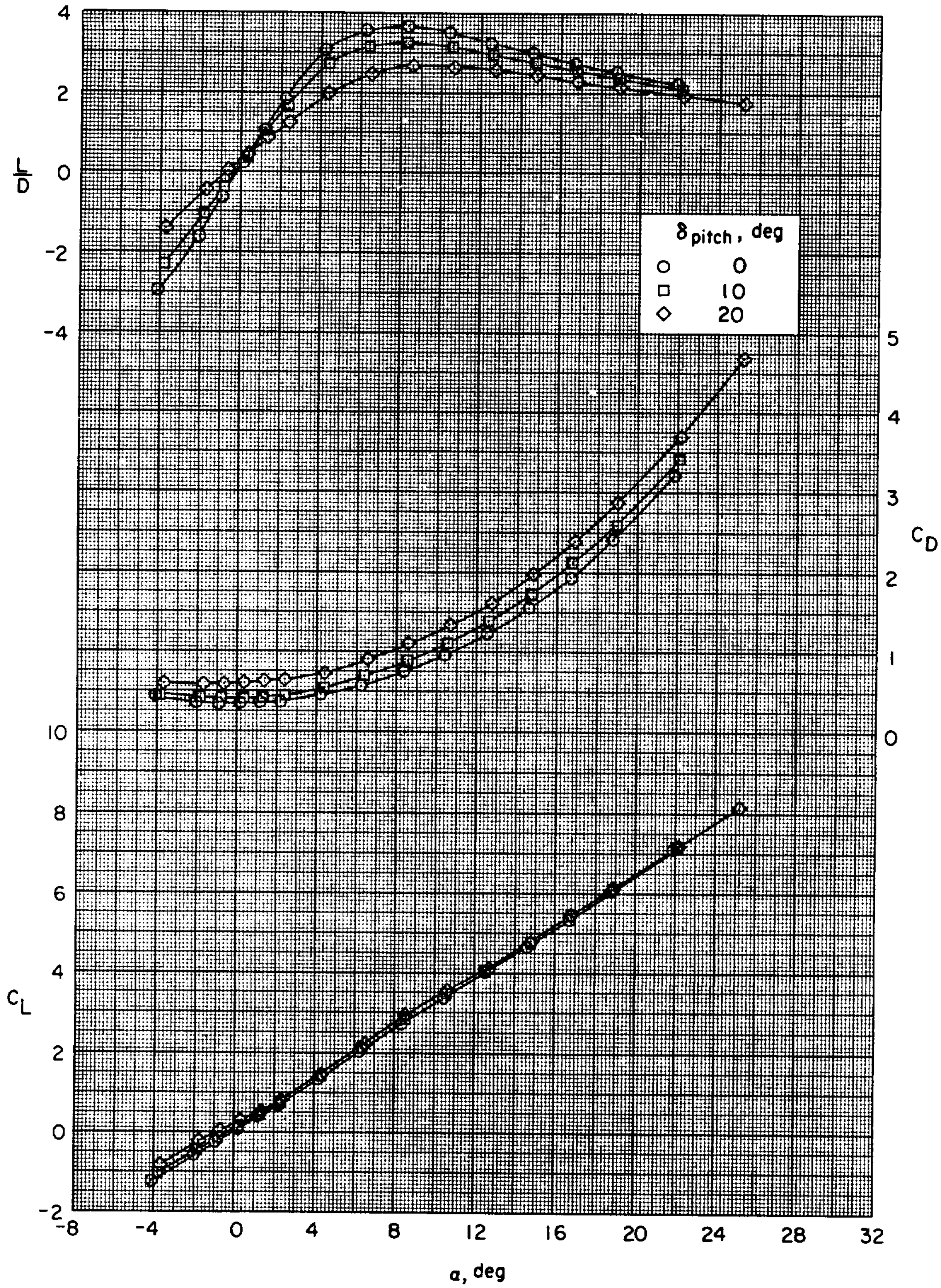
(b) Concluded.

Figure 4.- Continued.



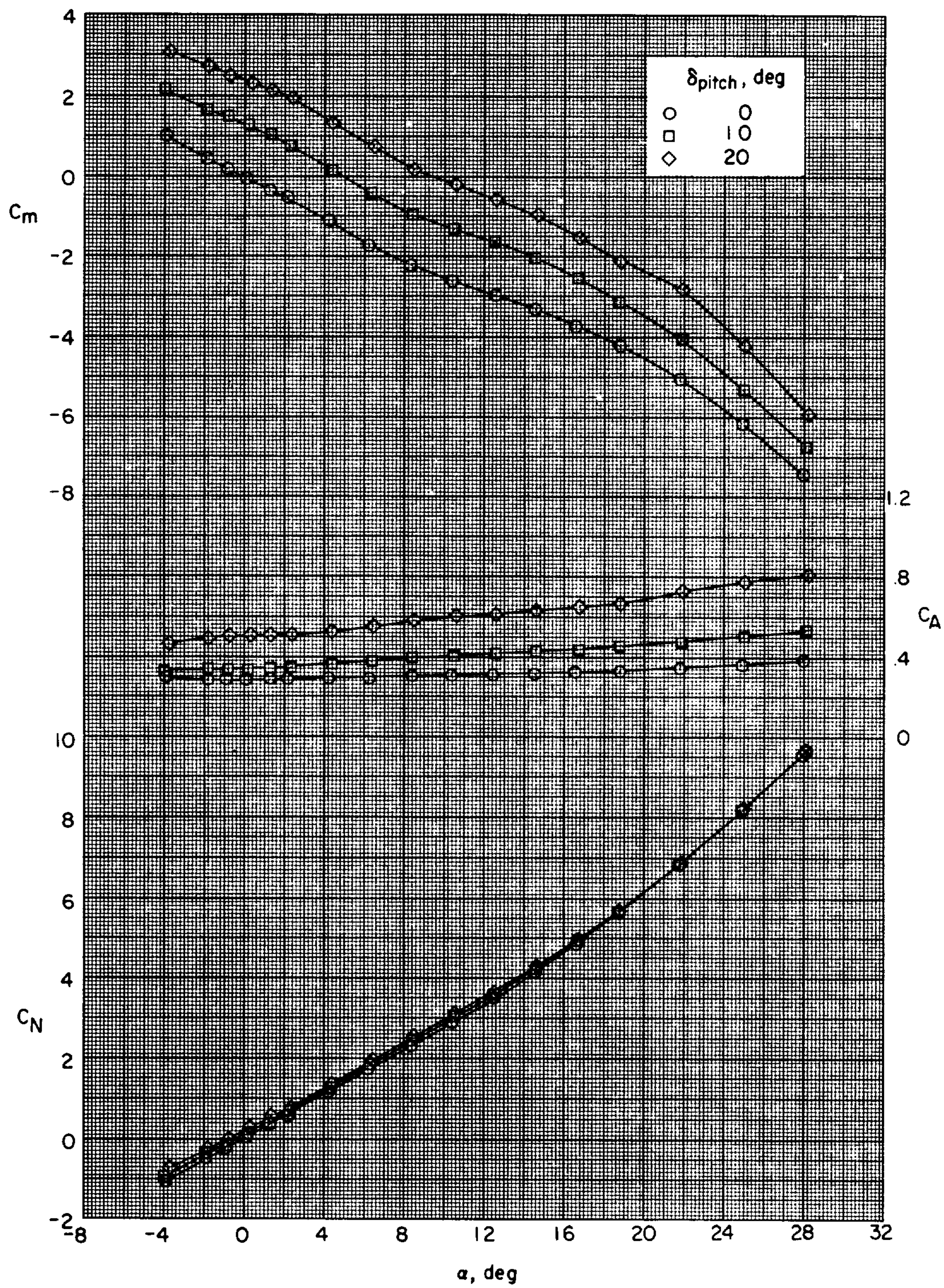
(c) M = 2.30.

Figure 4.- Continued.



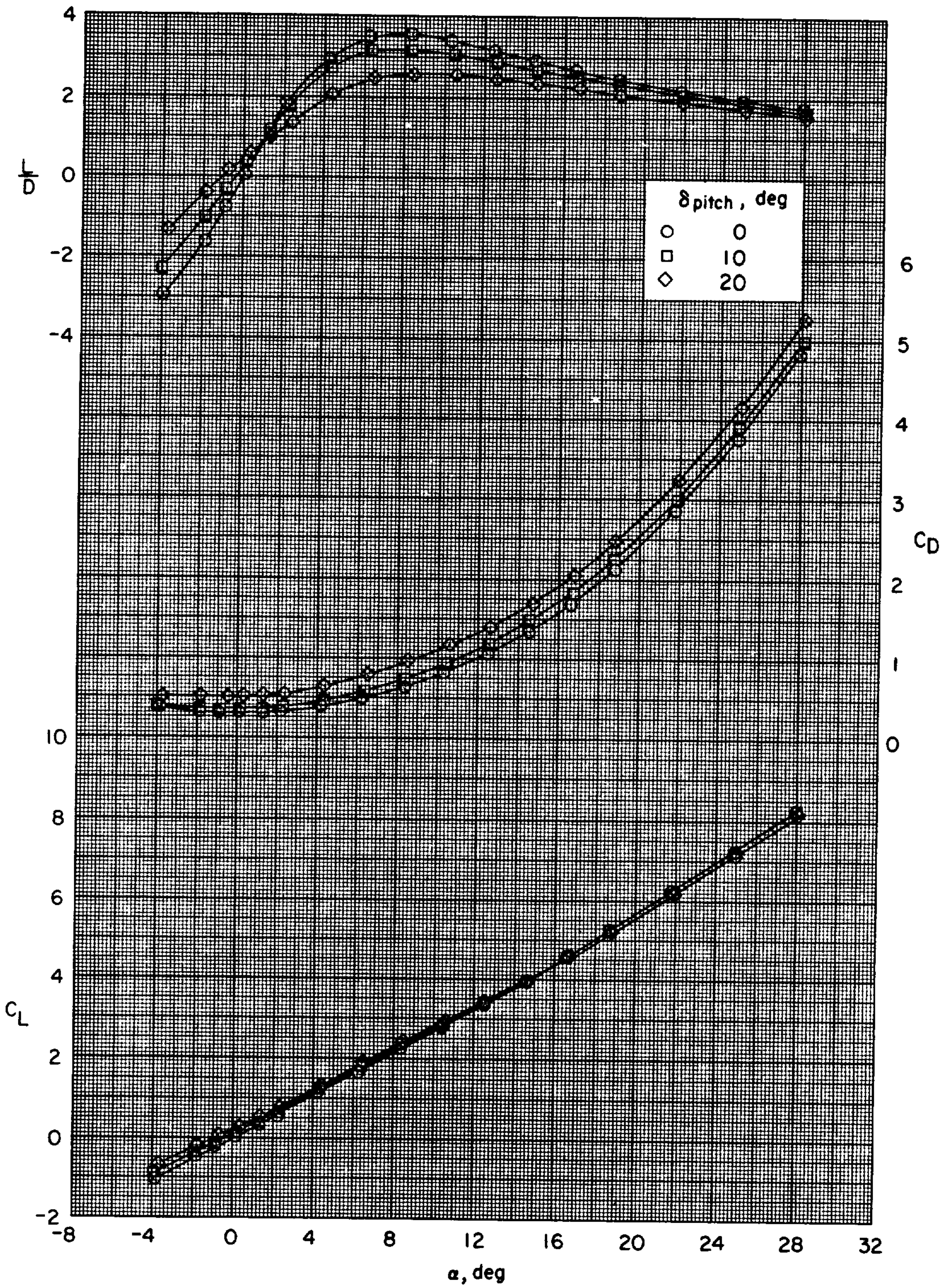
(c) Concluded.

Figure 4.- Continued.



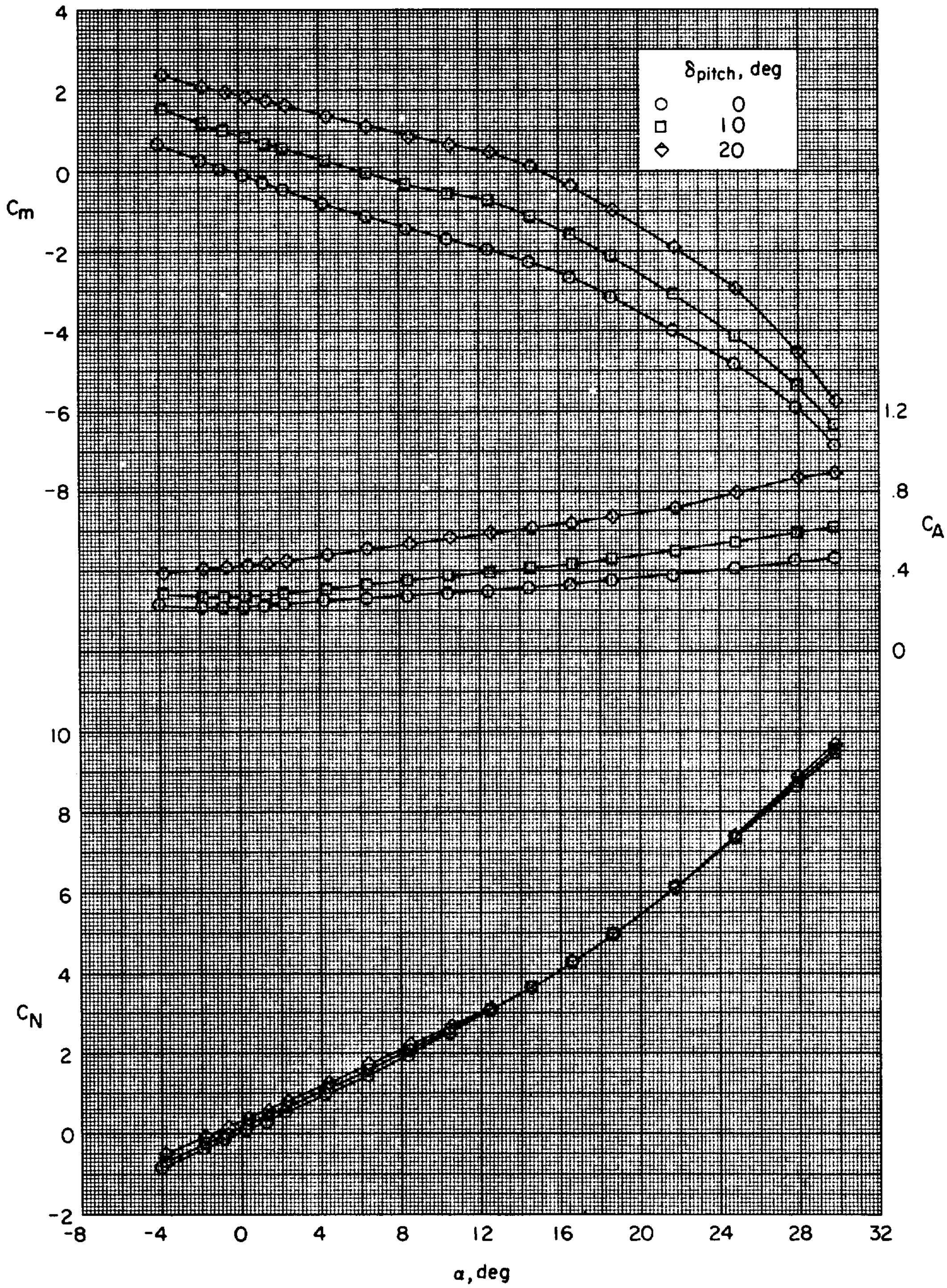
(d) M = 2.96.

Figure 4.- Continued.



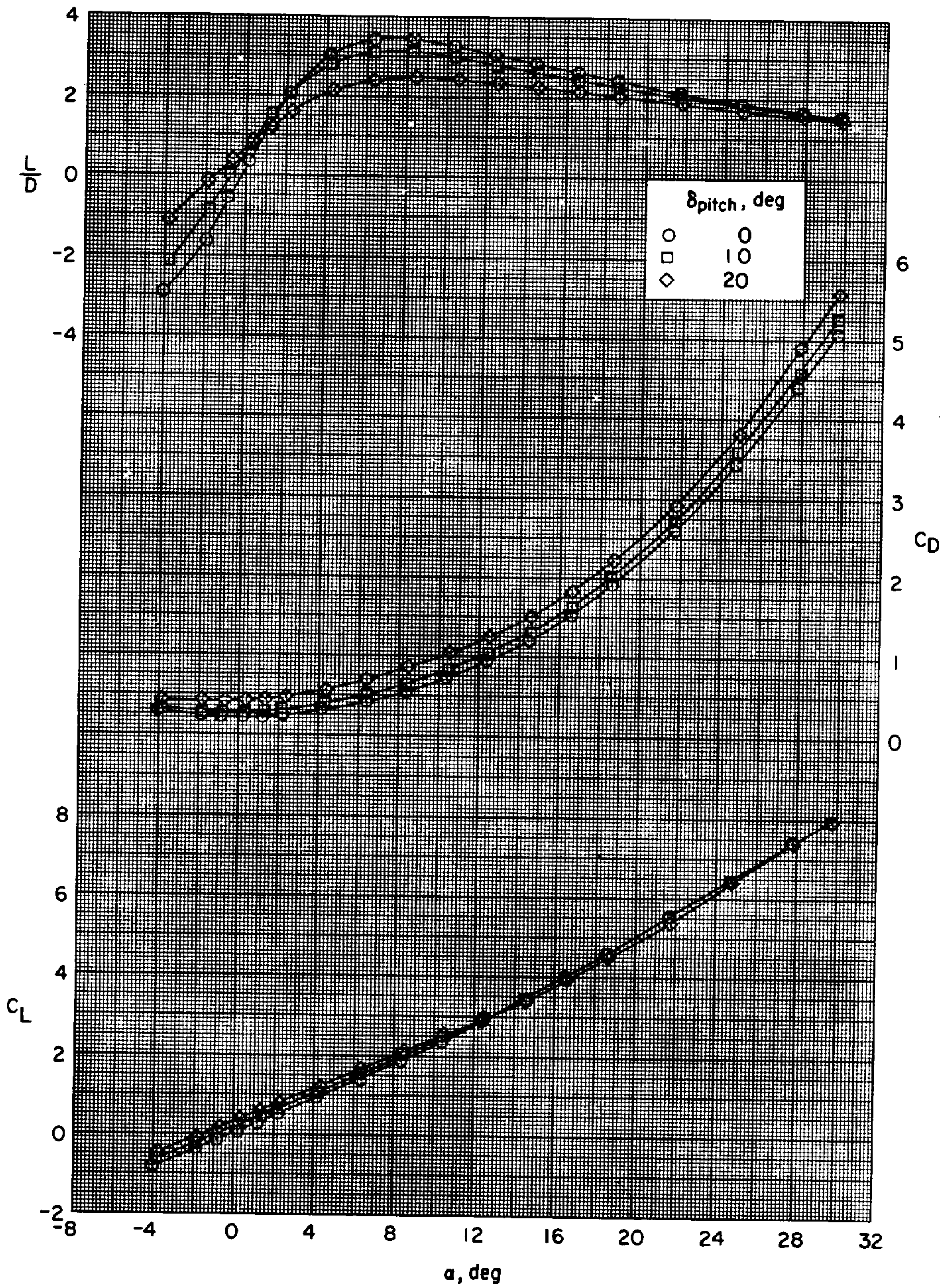
(d) Concluded.

Figure 4.- Continued.



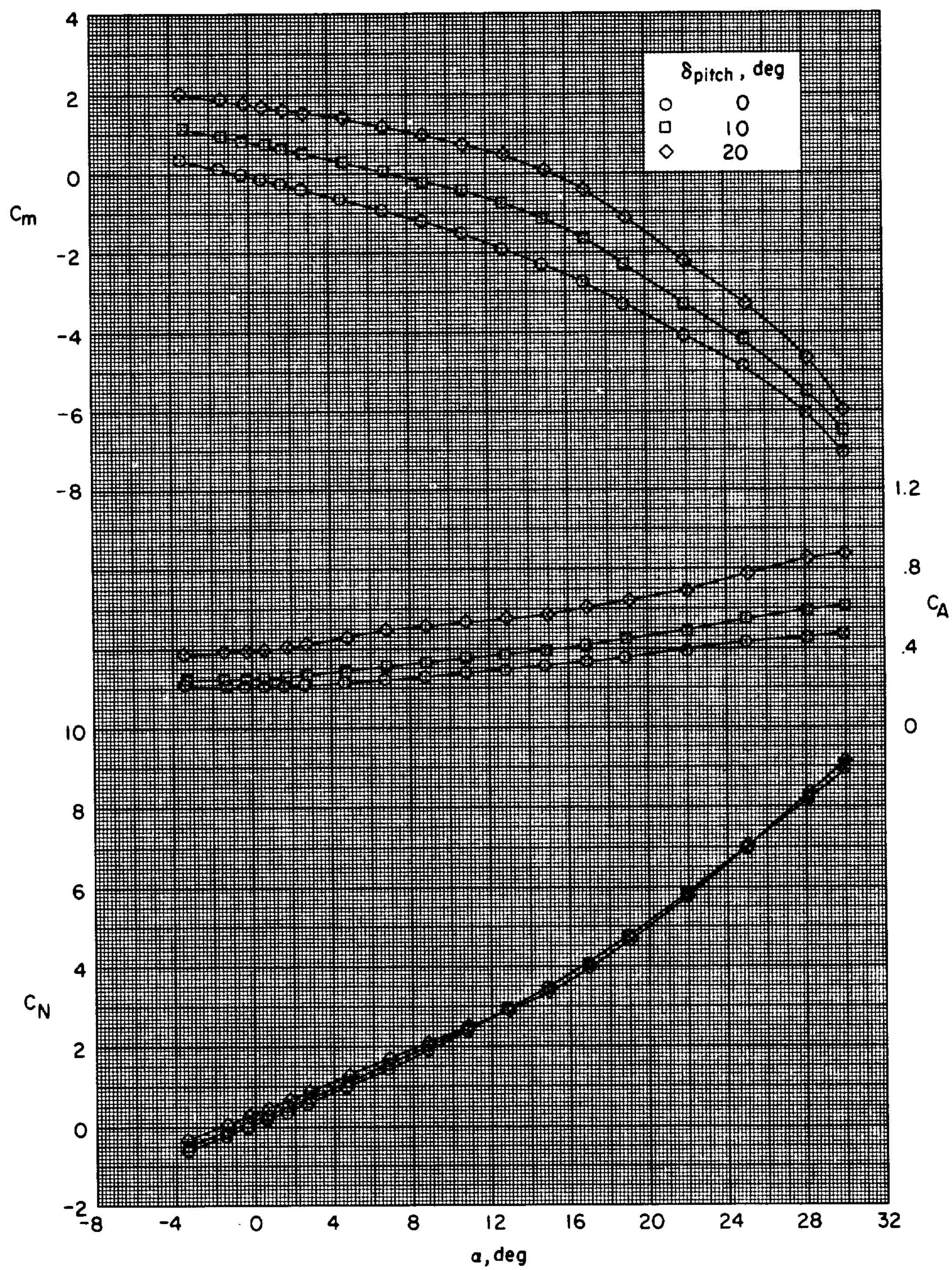
(e) M = 3.95.

Figure 4.- Continued.



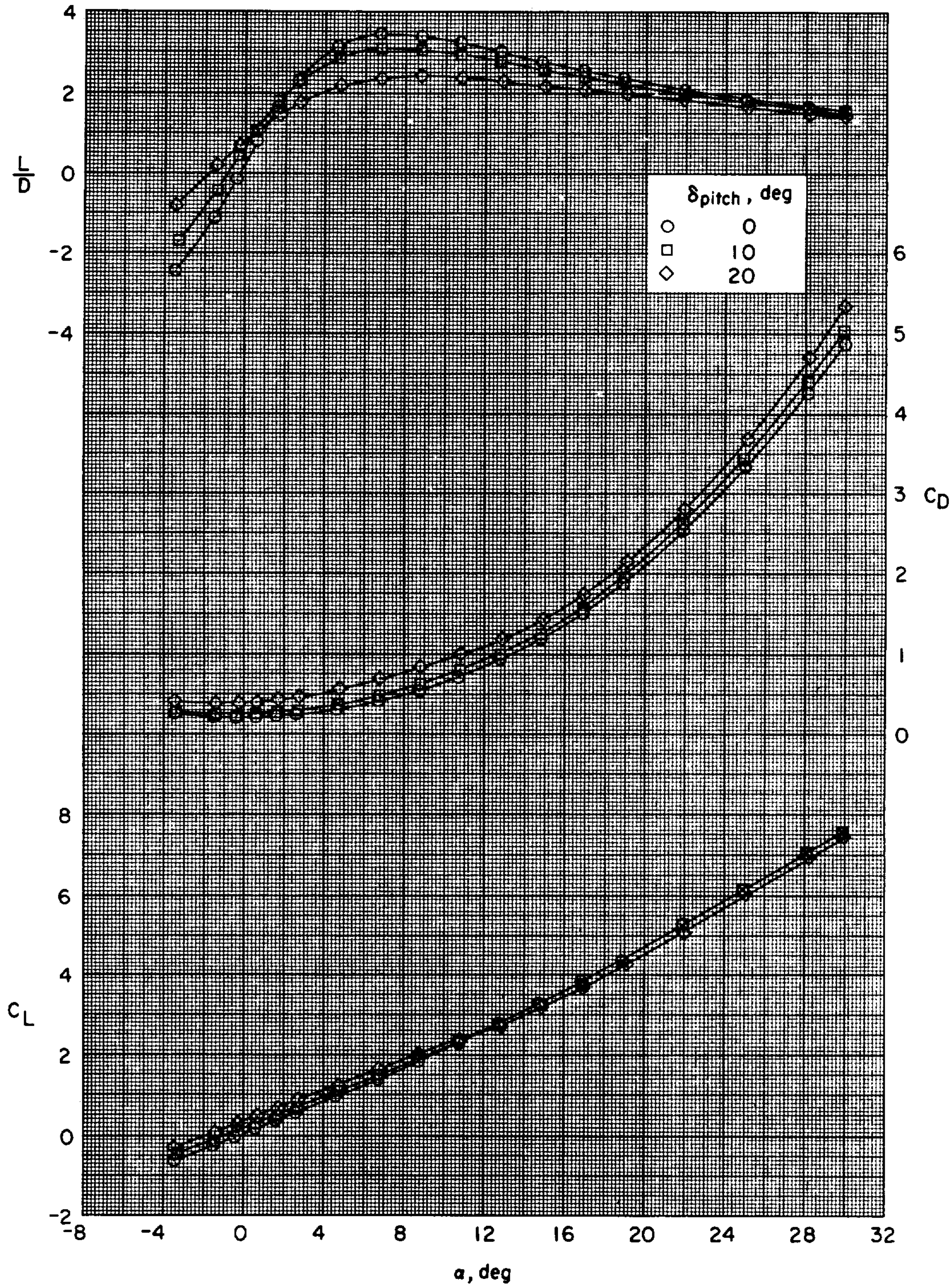
(e) Concluded.

Figure 4.- Continued.



(f) M = 4.63.

Figure 4.- Continued.



(f) Concluded.

Figure 4.- Concluded.

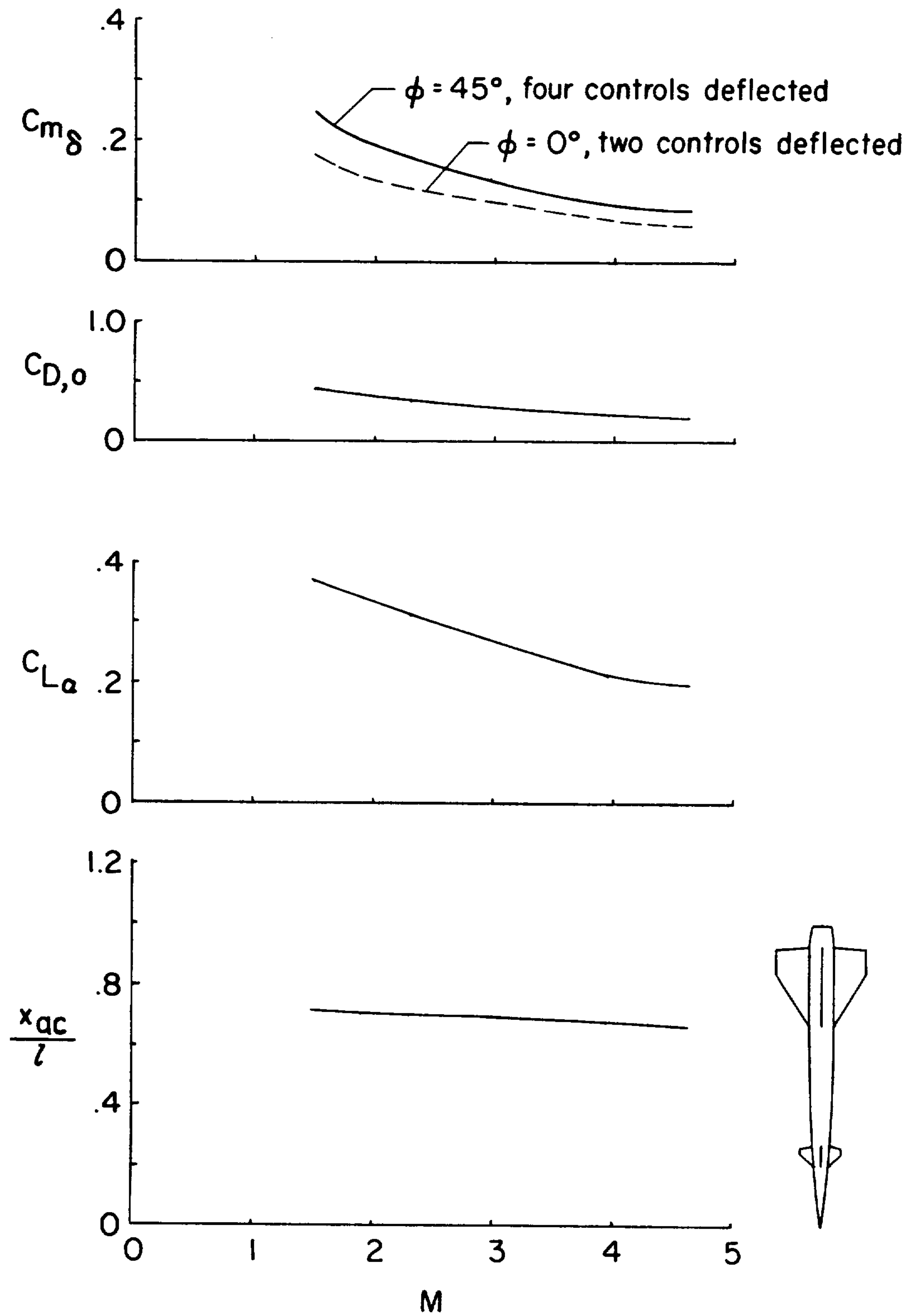


Figure 5.- Summary of the longitudinal aerodynamic characteristics.

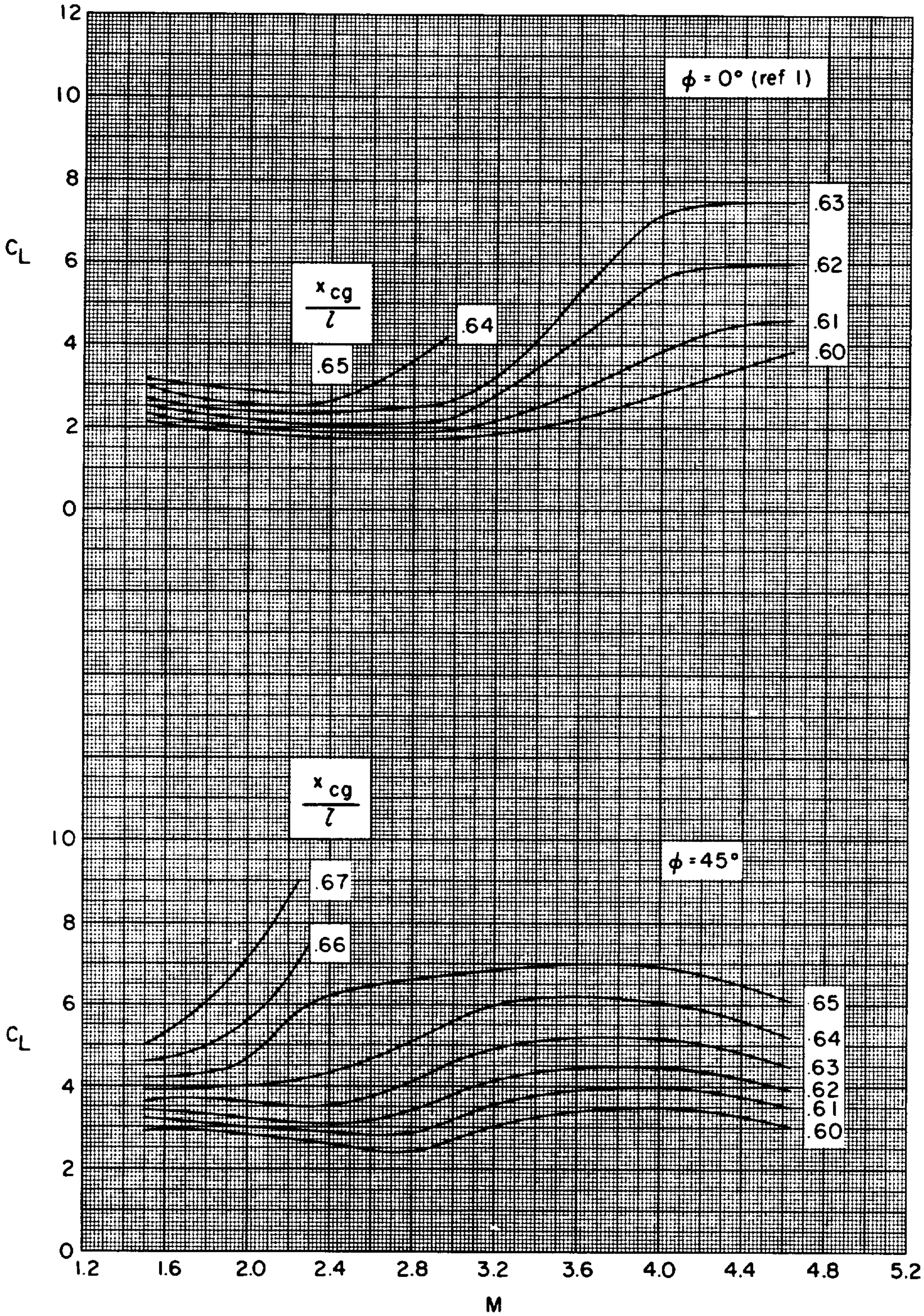
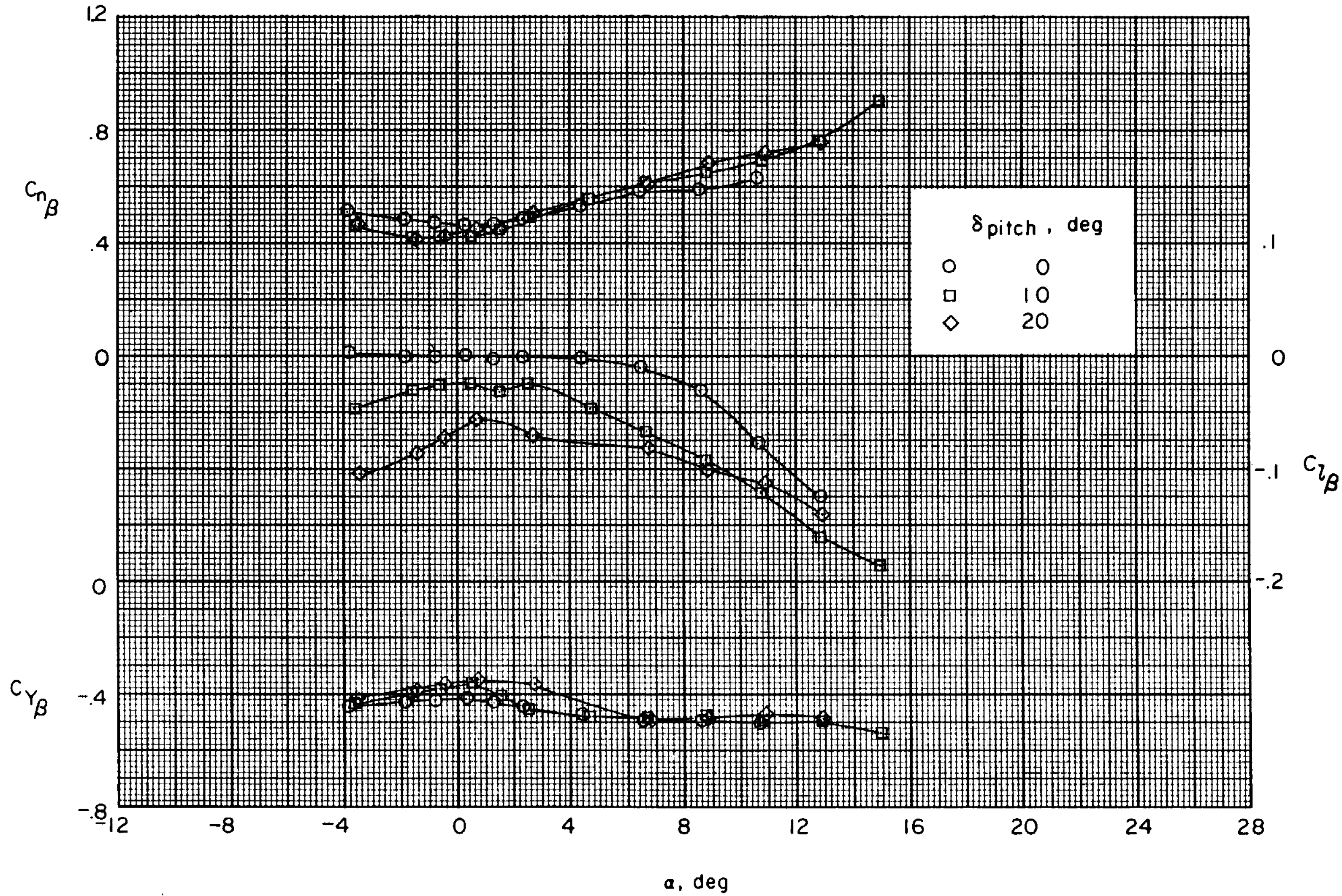


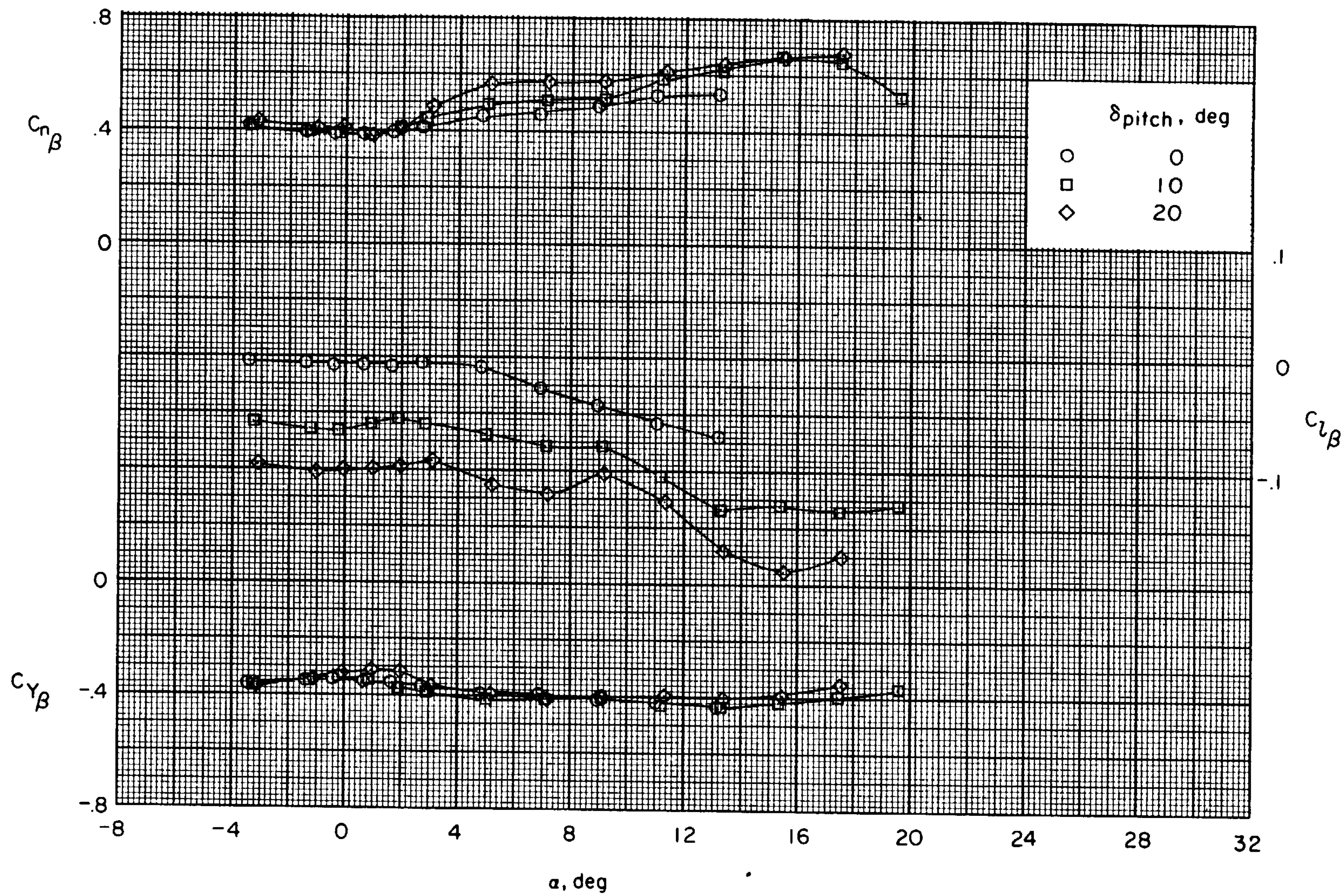
Figure 6.- Summary of longitudinal maneuvering characteristics. $\delta_c = 20^0$.



(a) M = 1.50.

Figure 7.- Effect of canard pitch-control deflection on the sideslip derivatives.

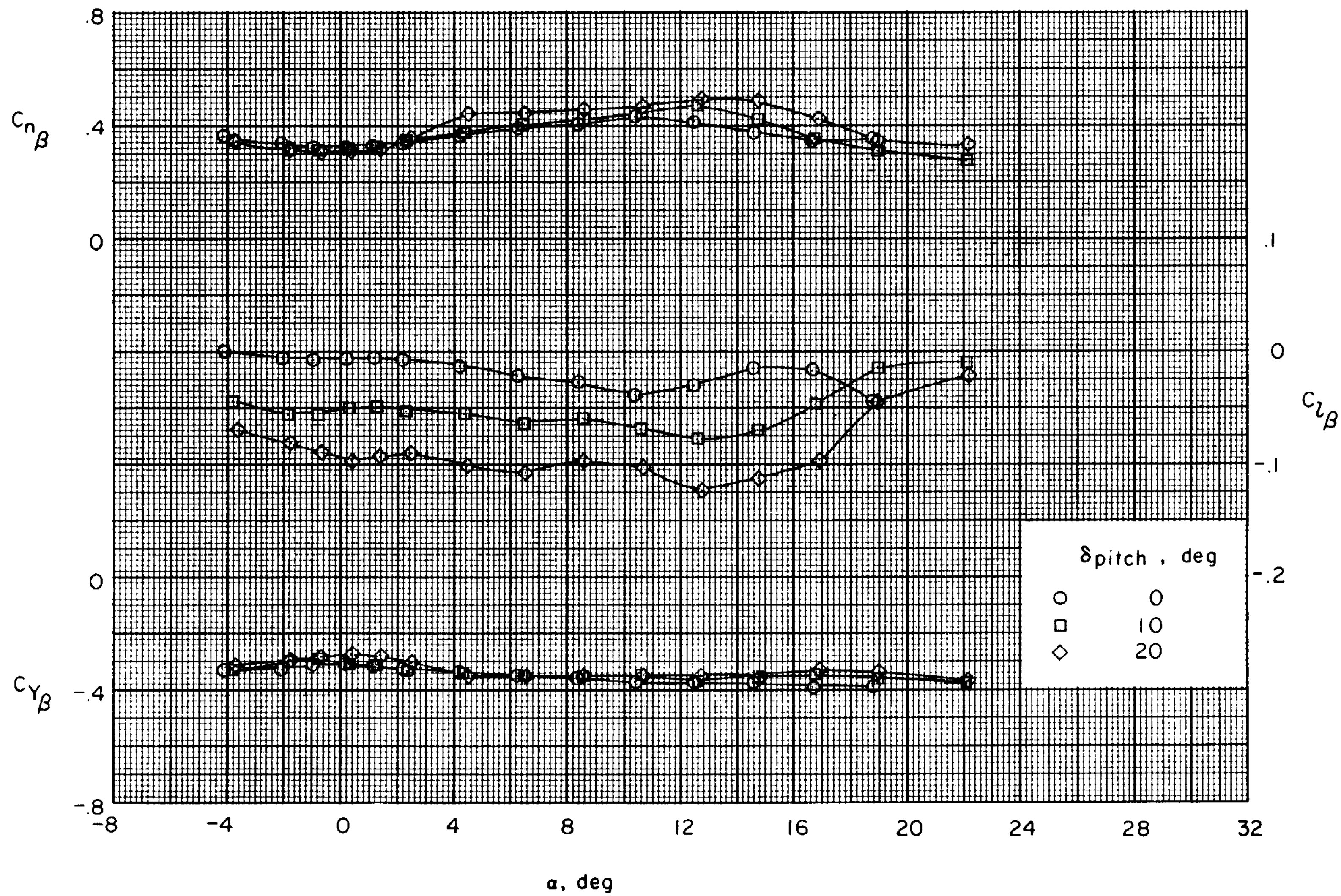
[redacted]



(b) M = 1.90.

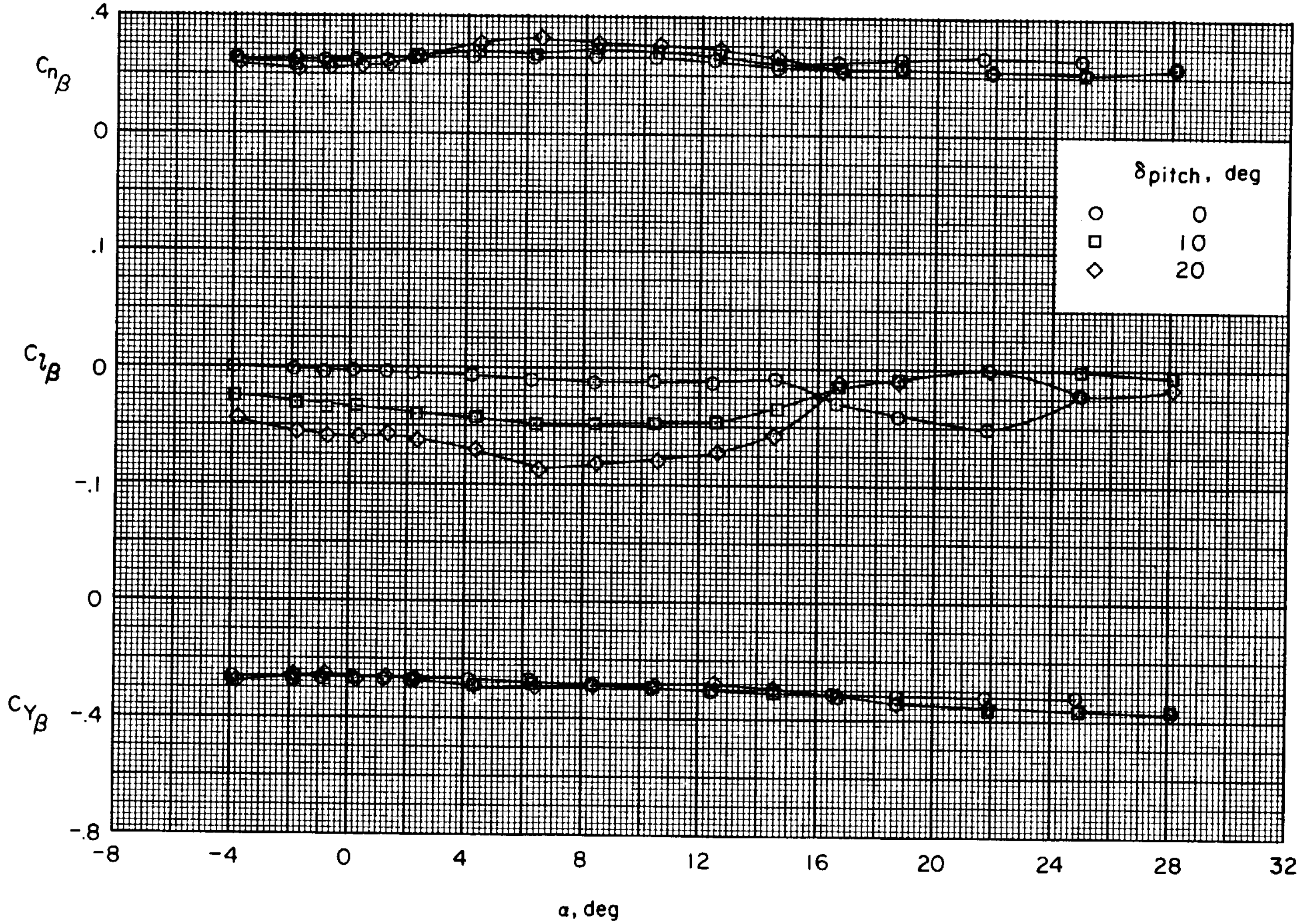
Figure 7.- Continued.

[redacted]



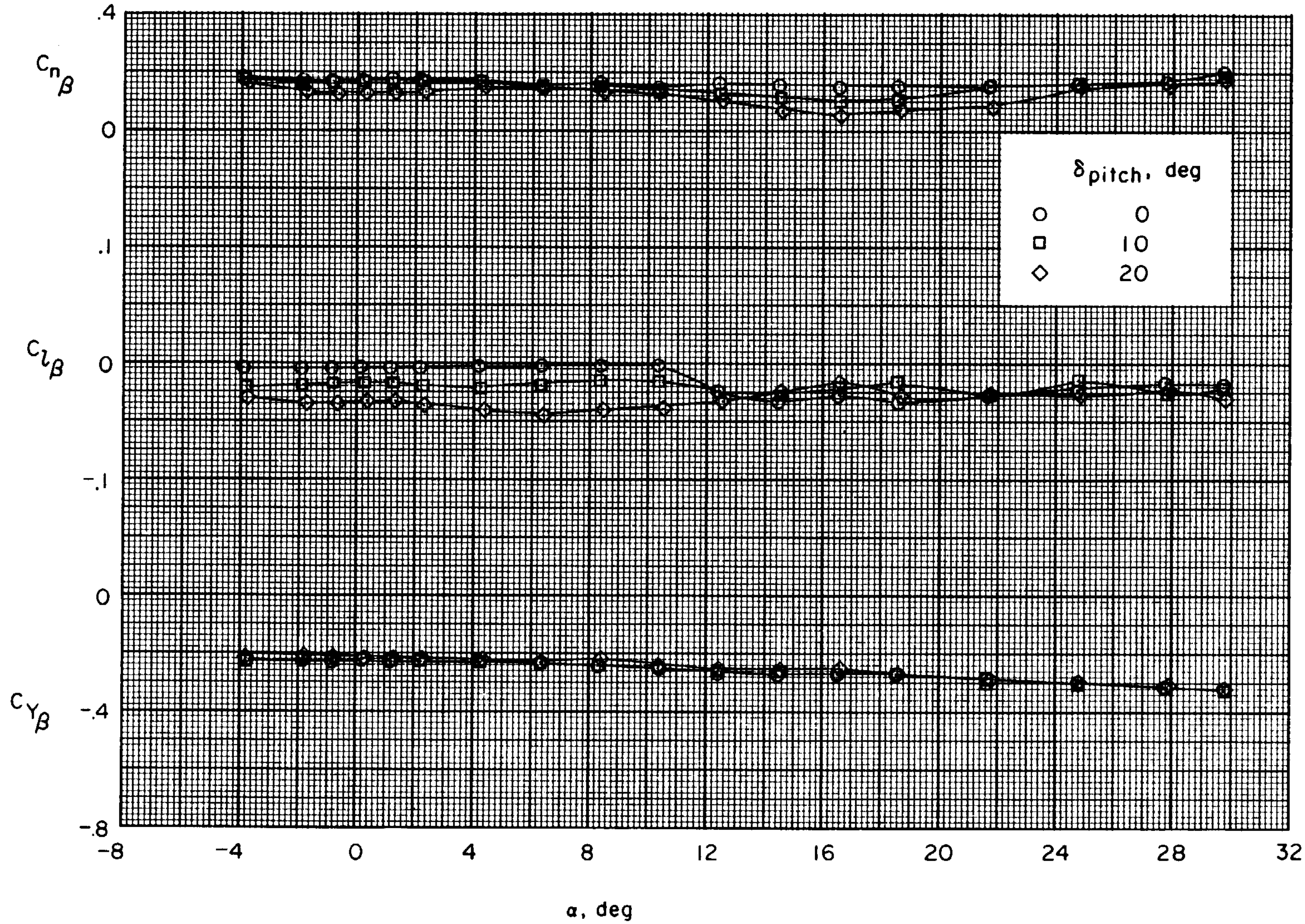
(c) M = 2.30.

Figure 7.- Continued.



(d) M = 2.96.

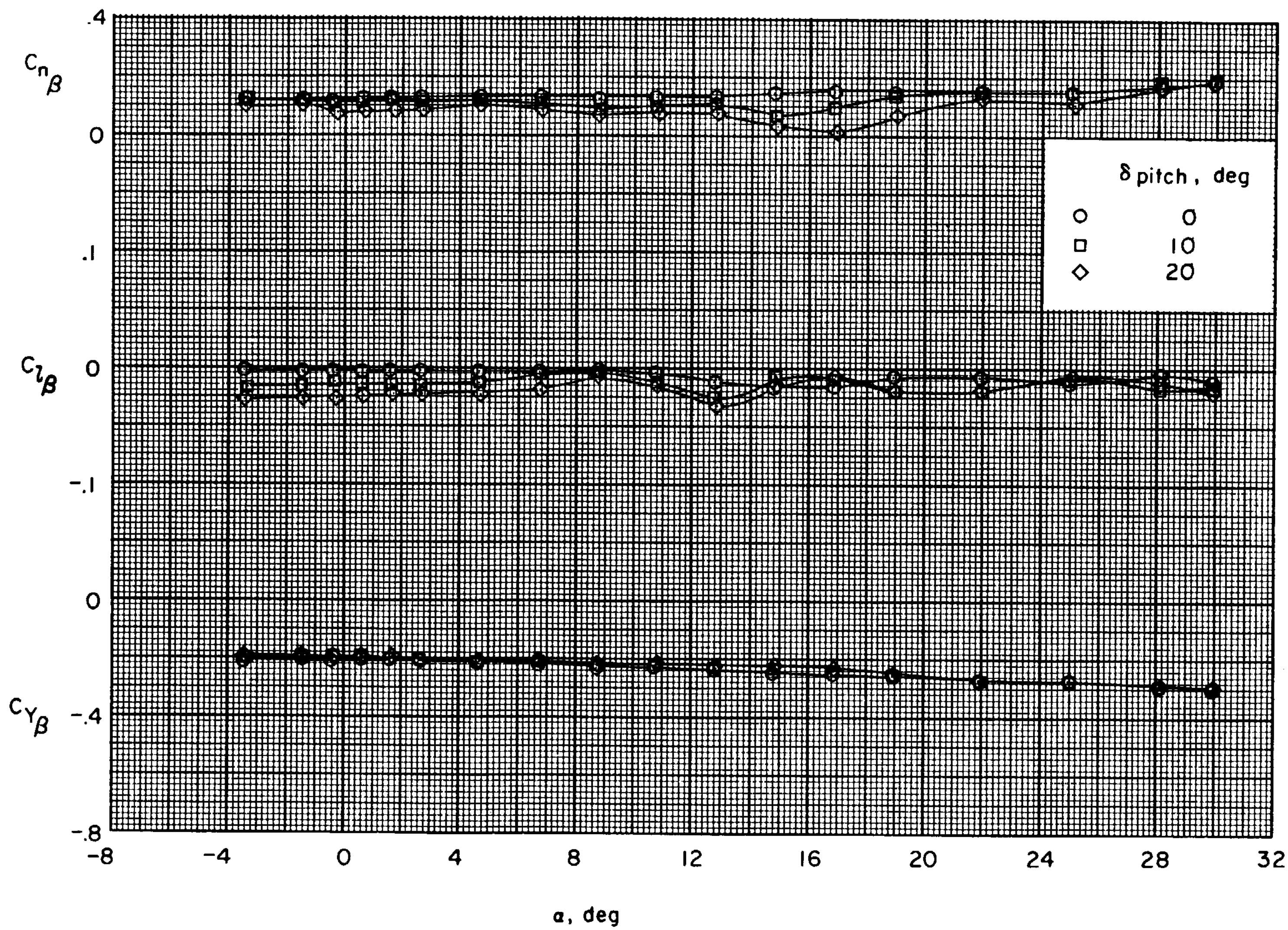
Figure 7.- Continued.



(e) M = 3.95.

Figure 7.- Continued.

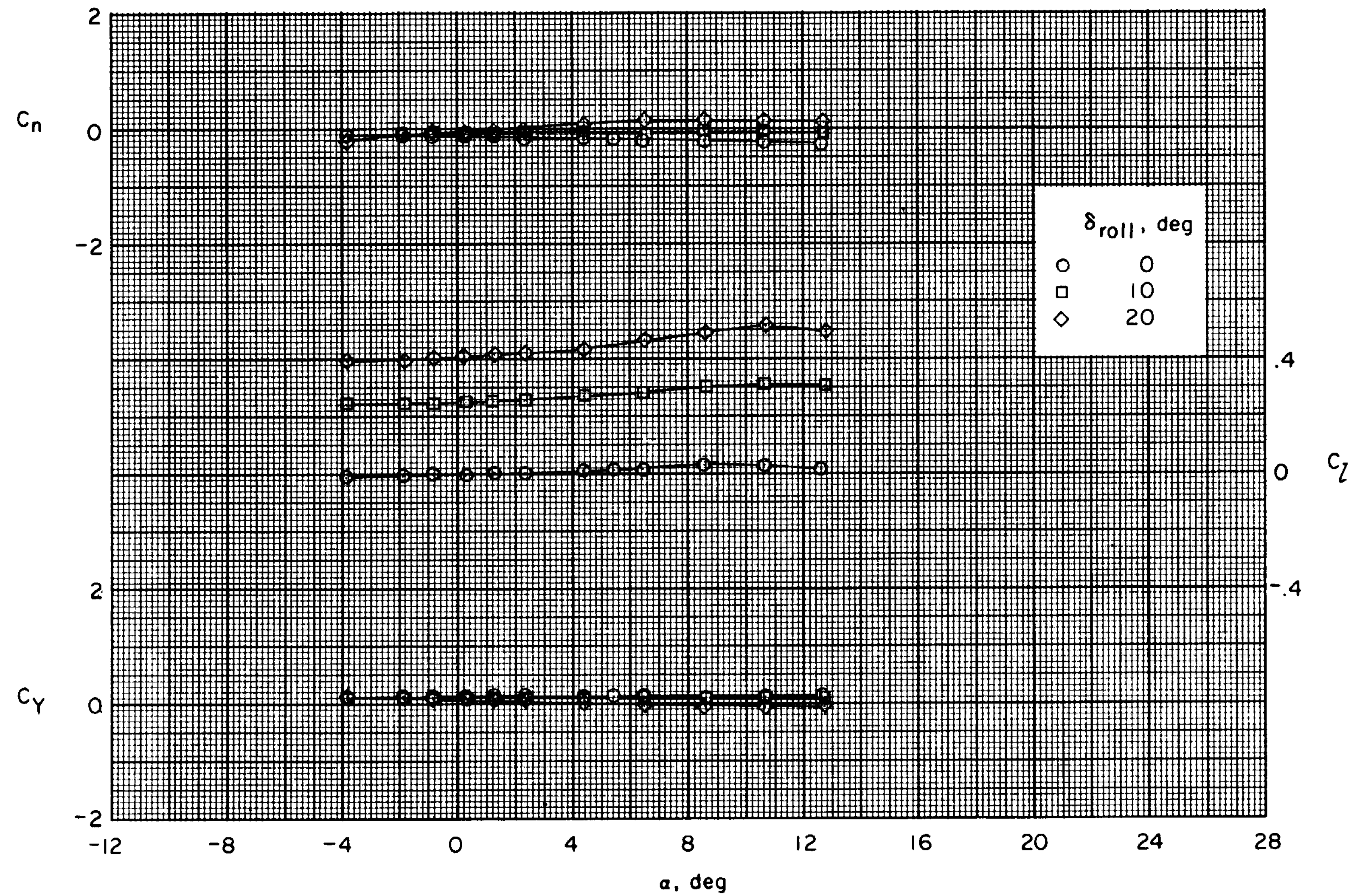
[redacted]



(f) M = 4.63.

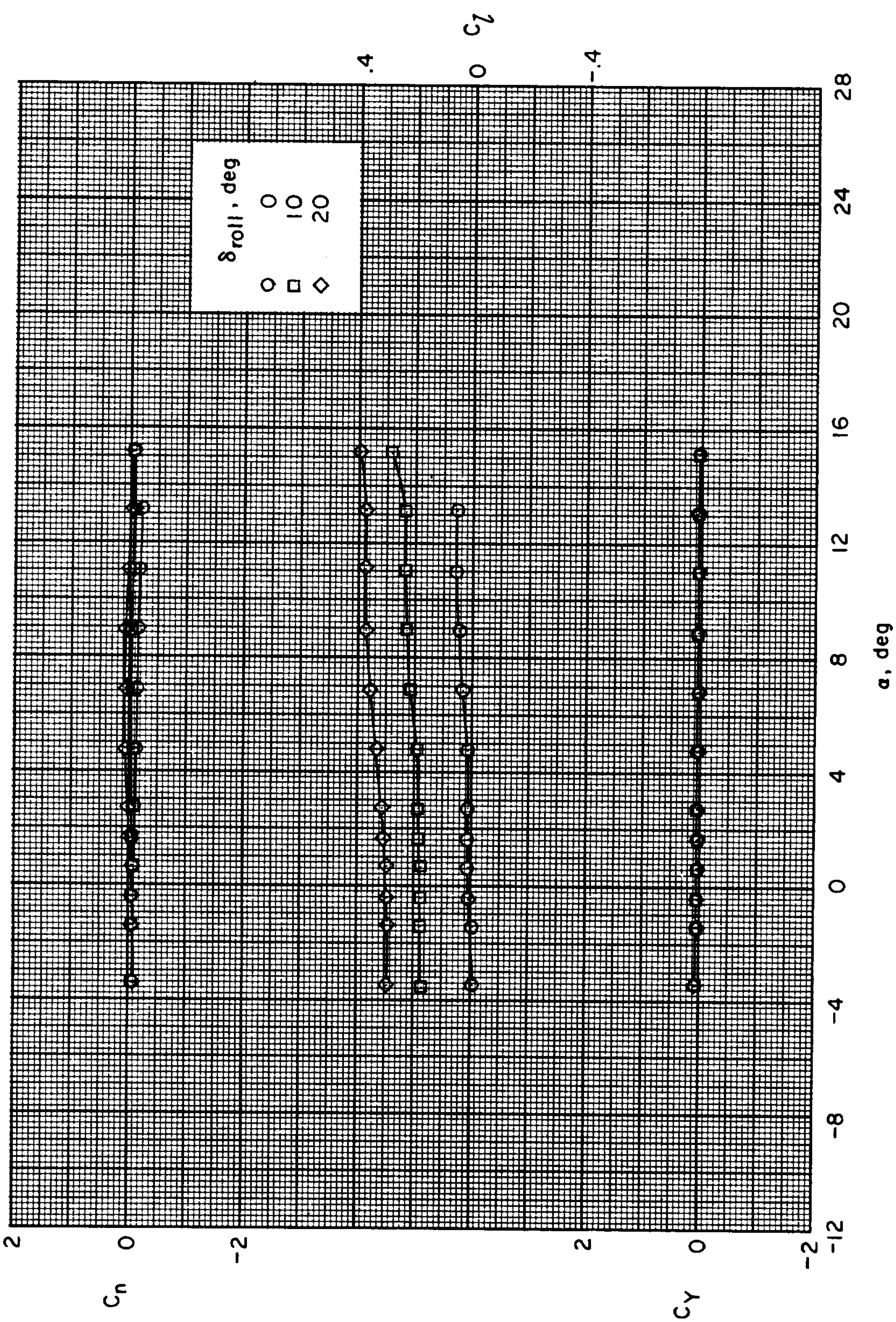
Figure 7.- Concluded.

[redacted]



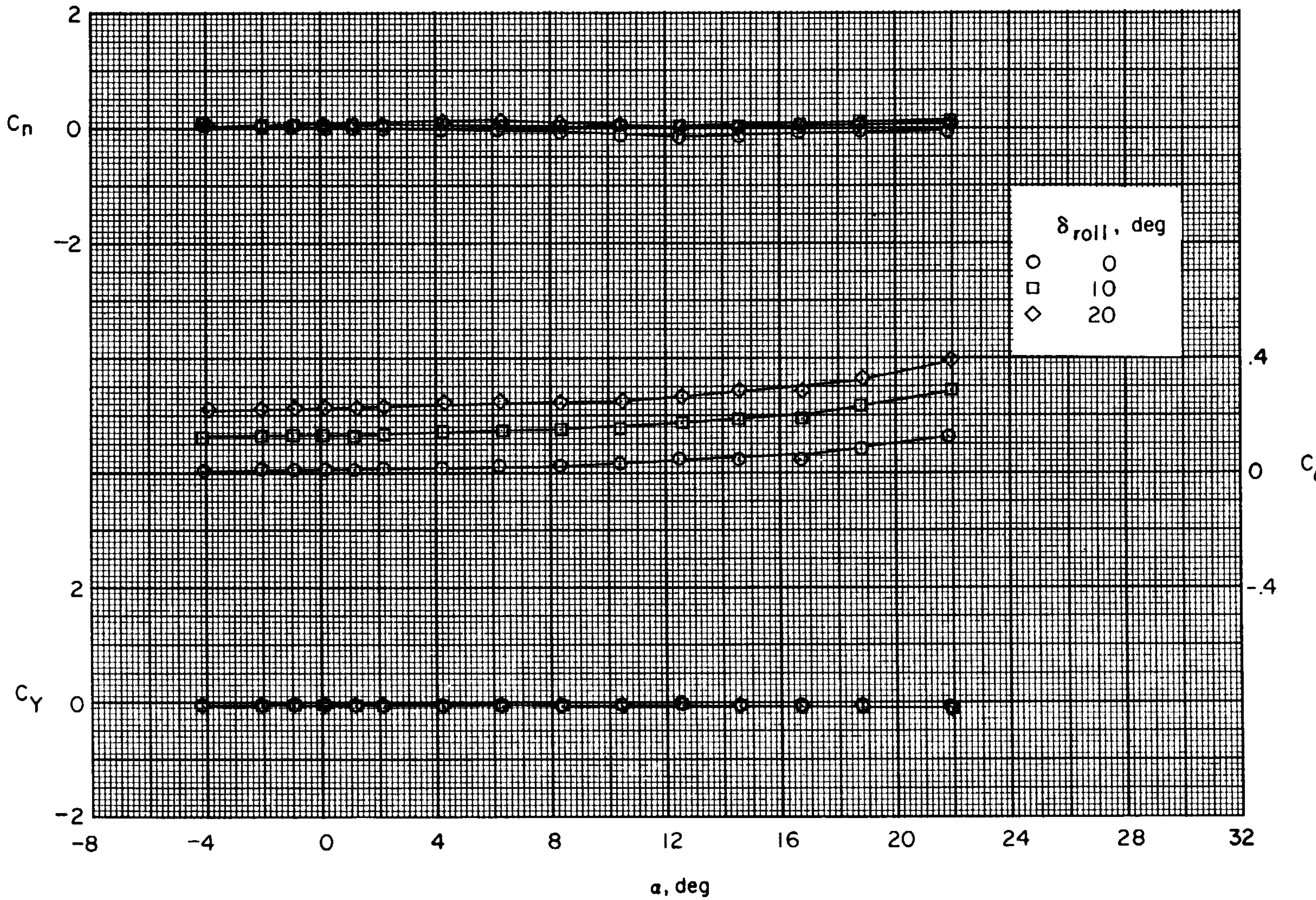
(a) M = 1.50.

Figure 8.- Effect of wing deflection on the roll-control characteristics.



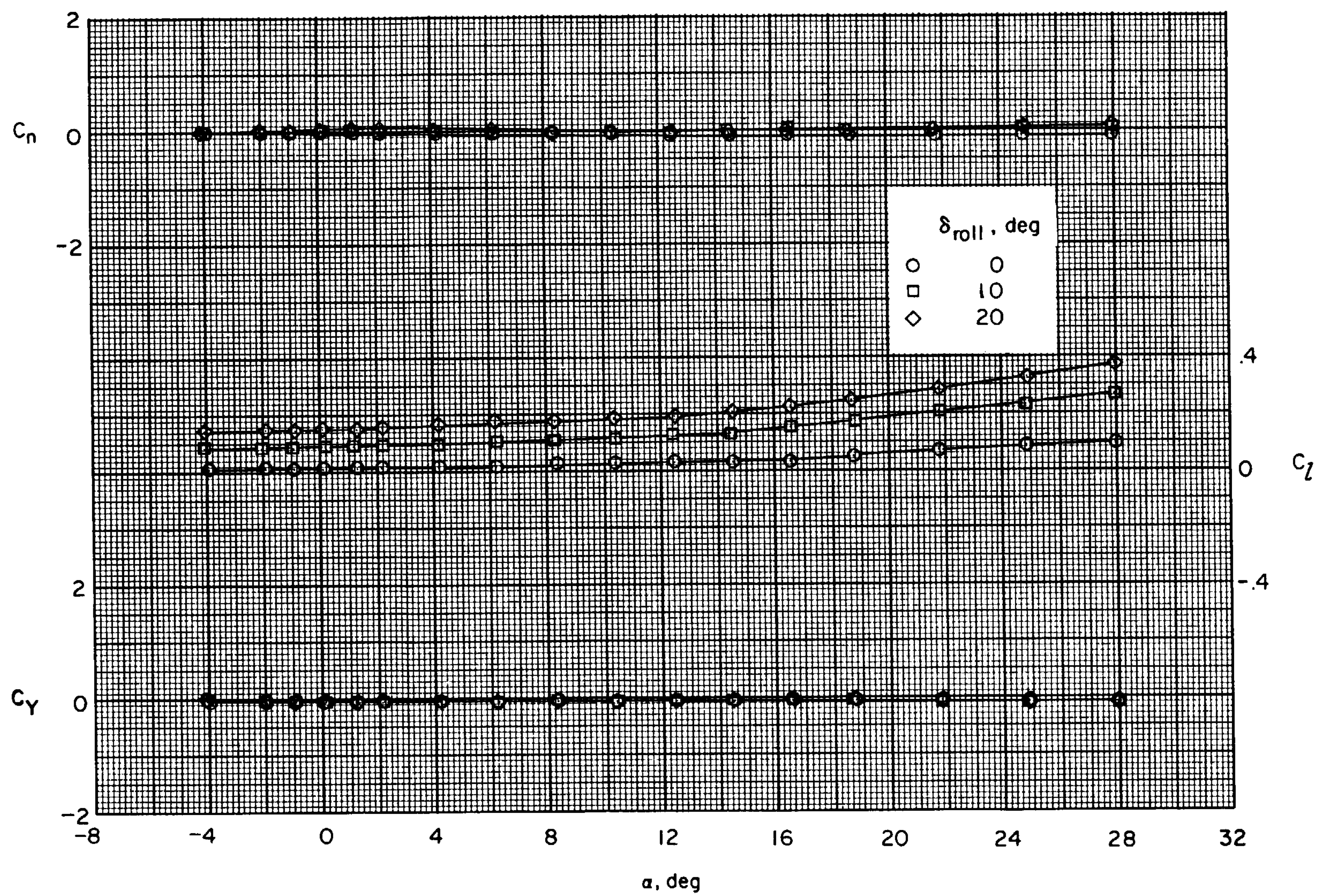
(b) M = 1.90.

Figure 8.- Continued.



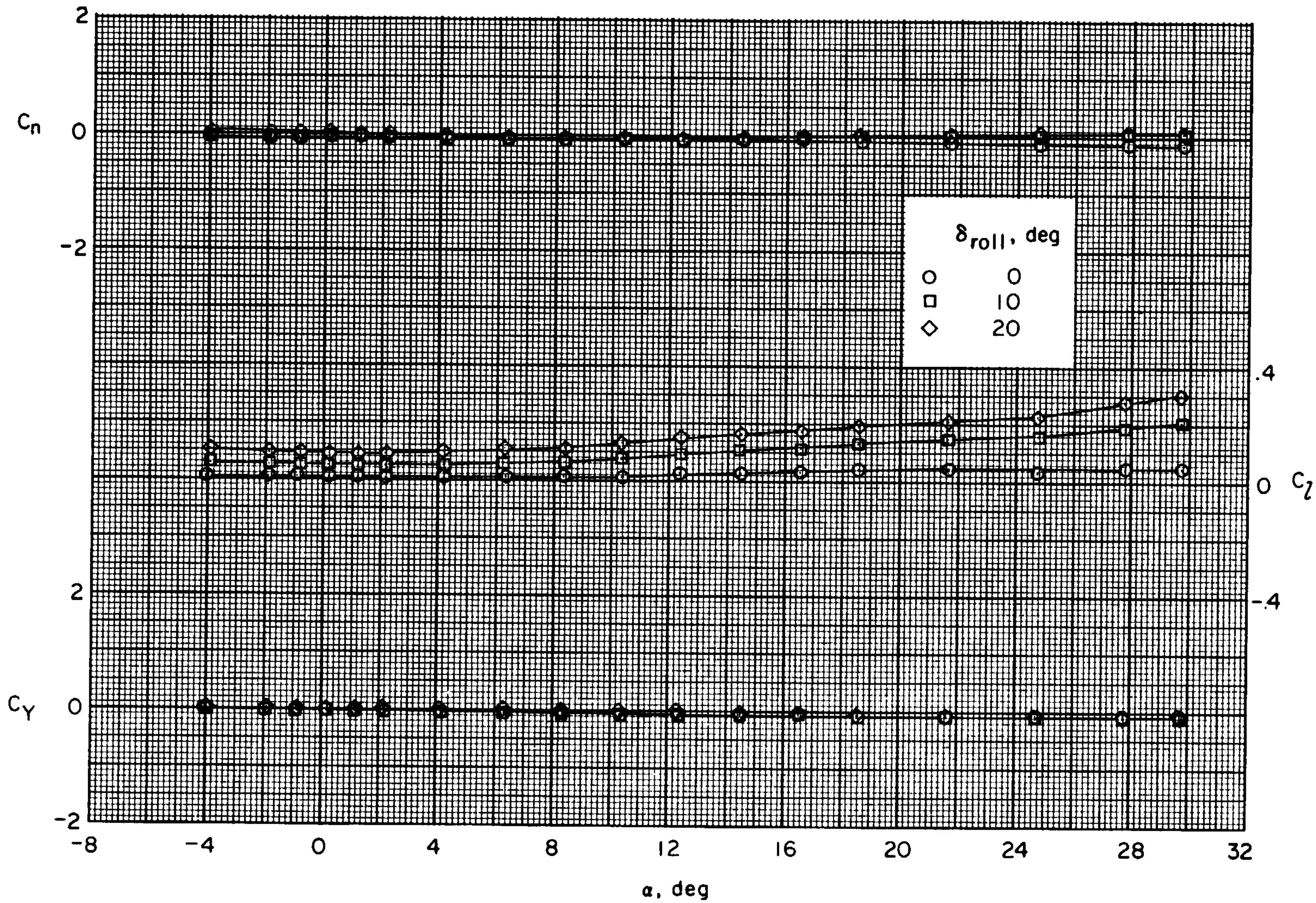
(c) M = 2.30.

Figure 8.- Continued.



(d) M = 2.96.

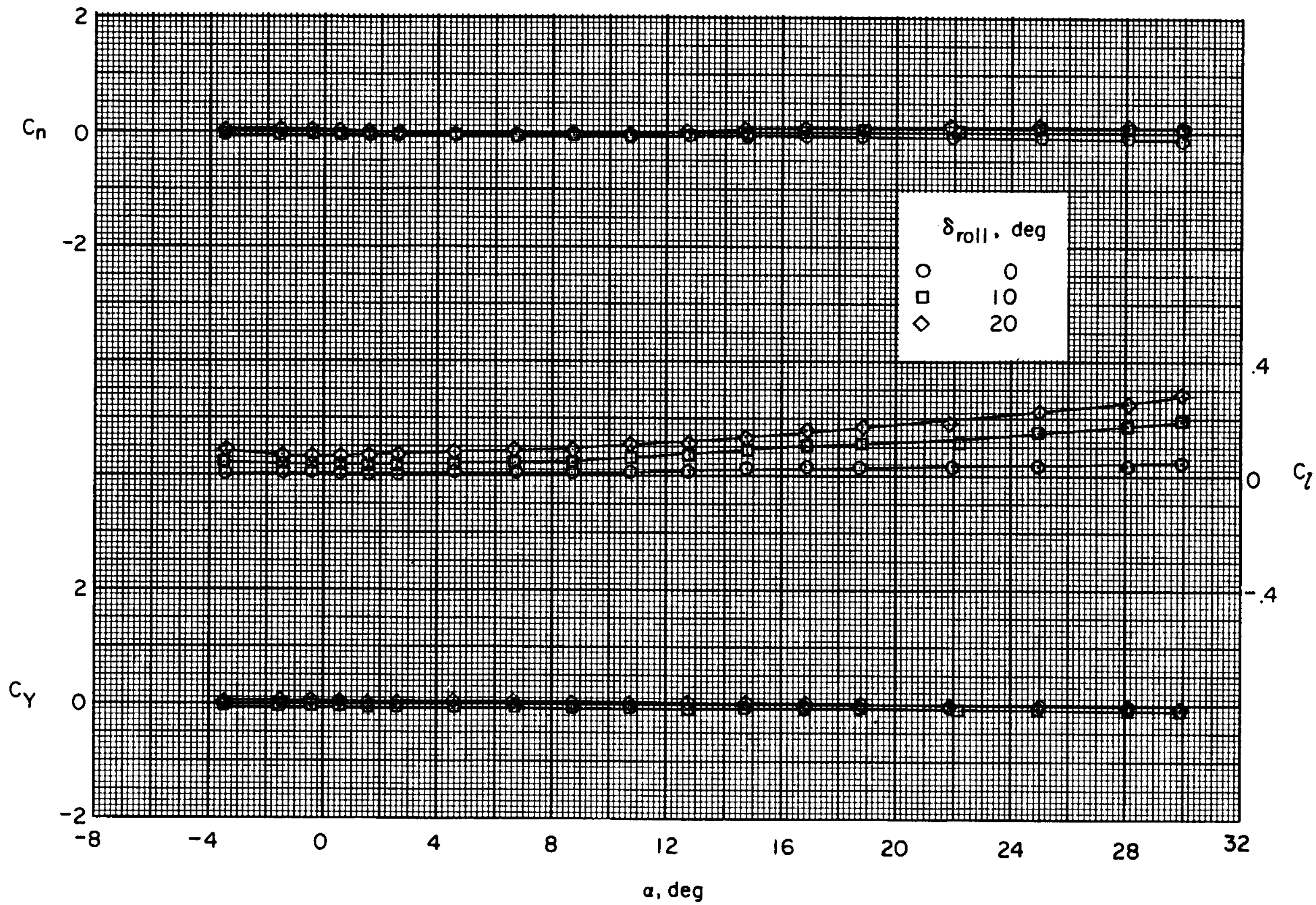
Figure 8.- Continued.



(e) M = 3.95.

Figure 8.- Continued.

[redacted]

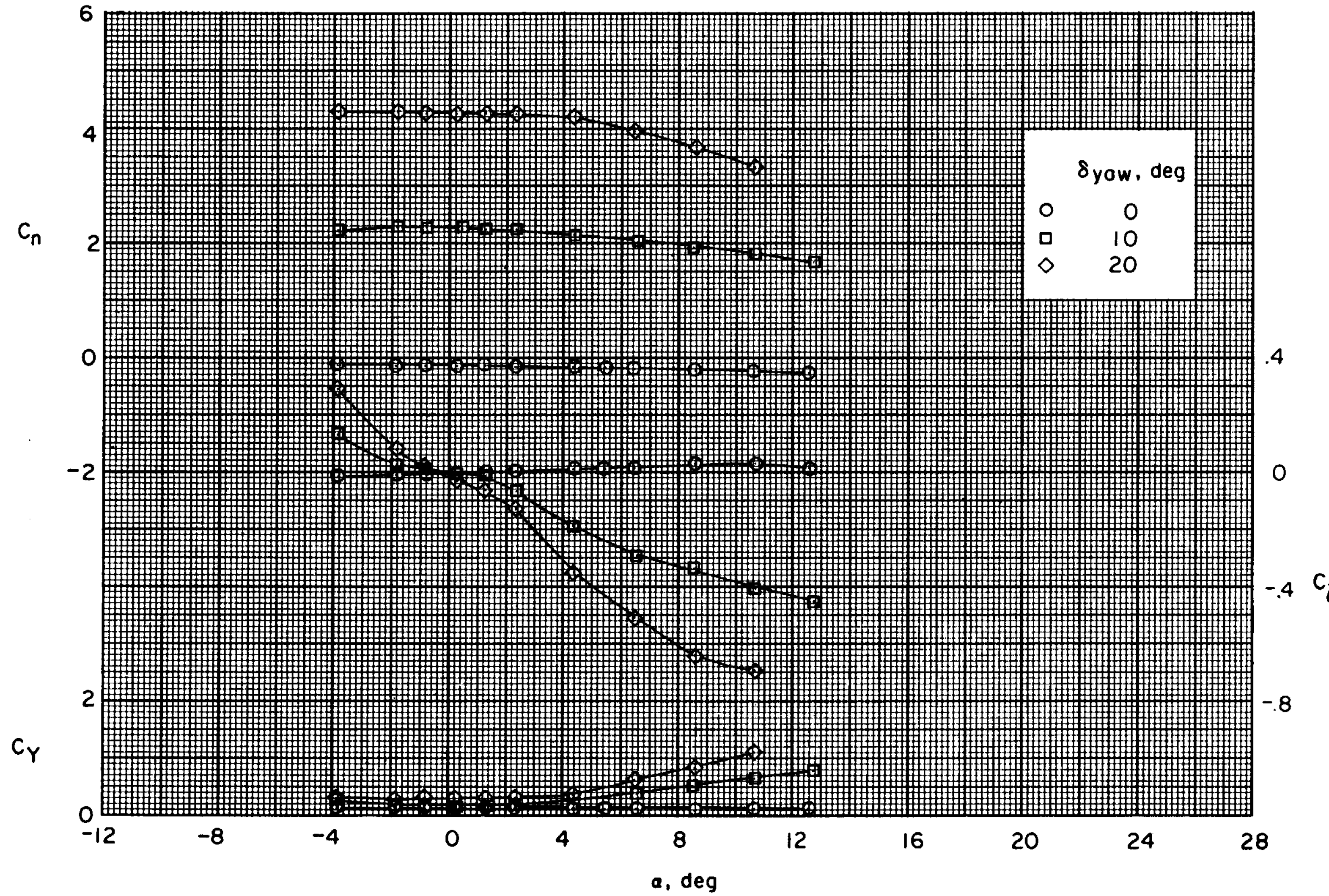


(f) M = 4.63.

Figure 8.- Concluded.

[redacted]

[redacted]

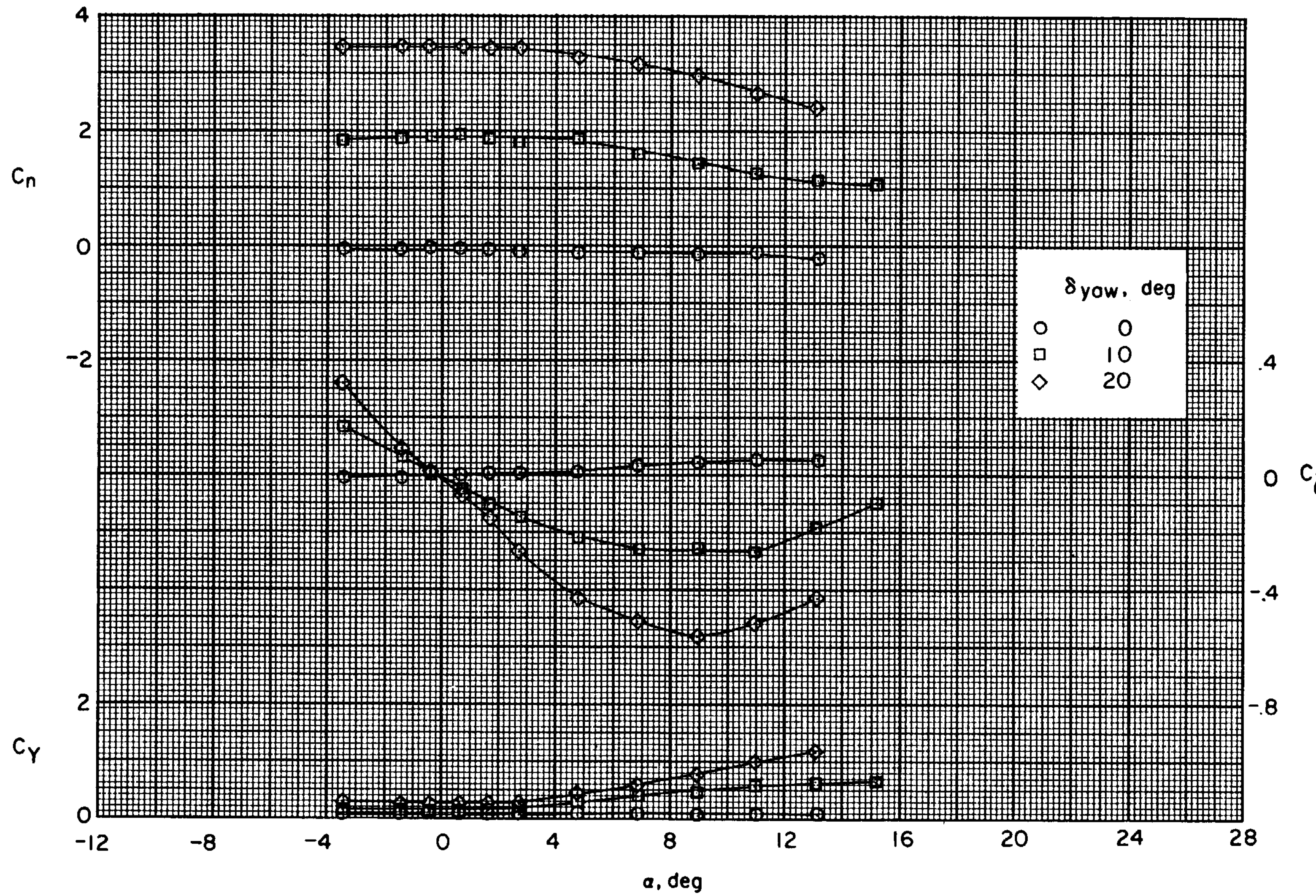


(a) M = 1.50.

Figure 9.- Effect of canard yaw-control deflection on the yaw-control characteristics.

[redacted]

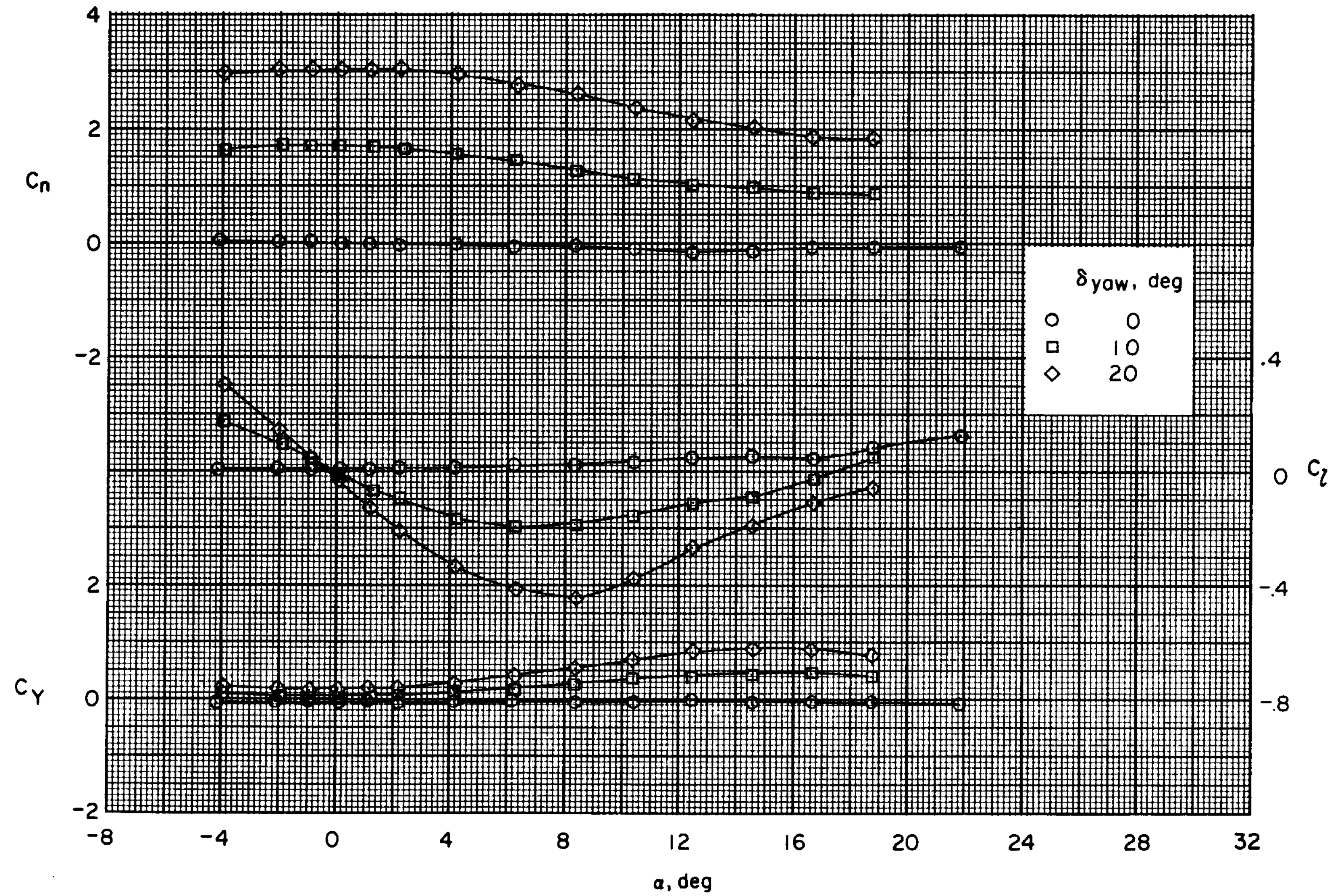
[redacted]



(b) M = 1.90.

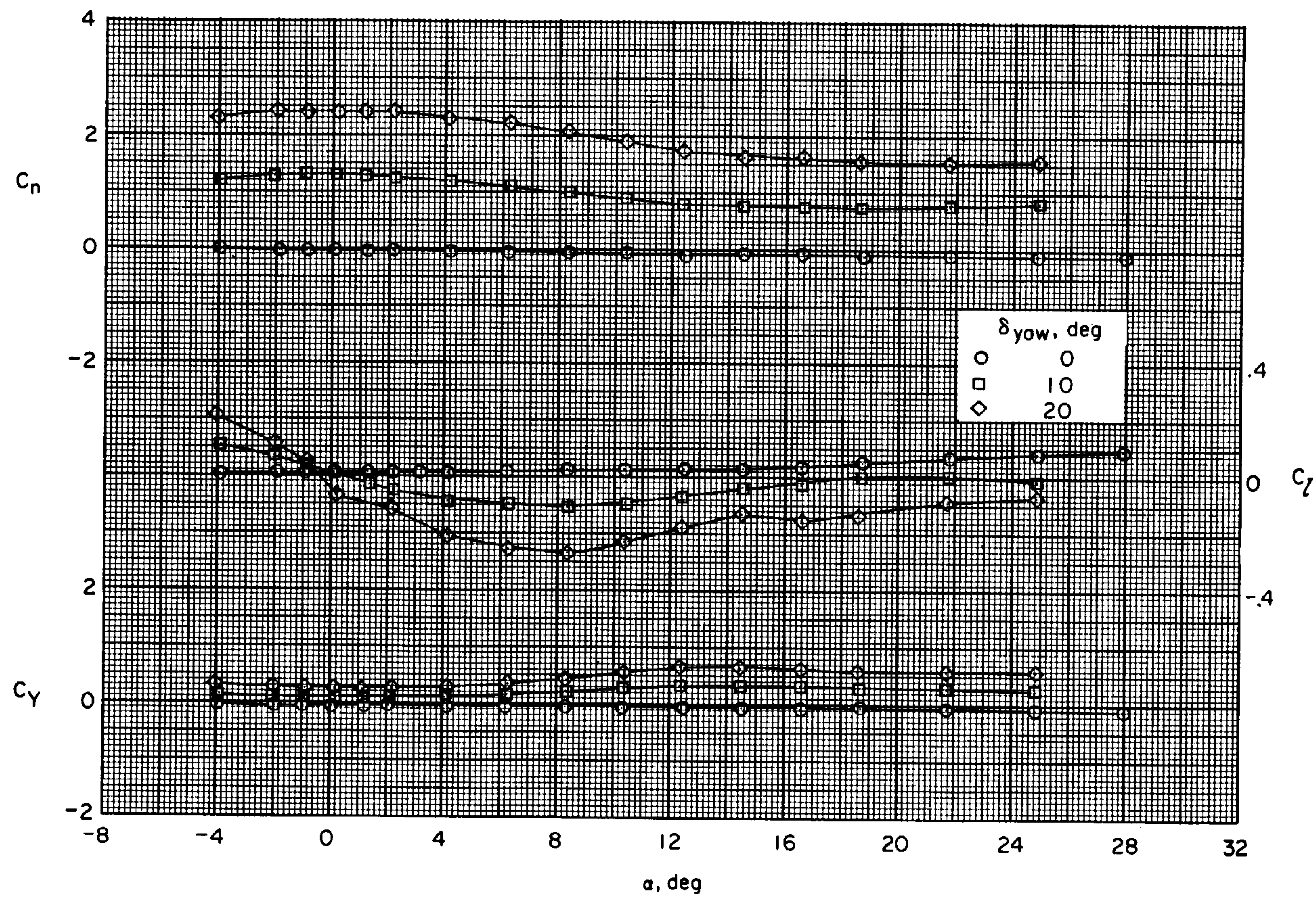
Figure 9.- Continued.

[redacted]



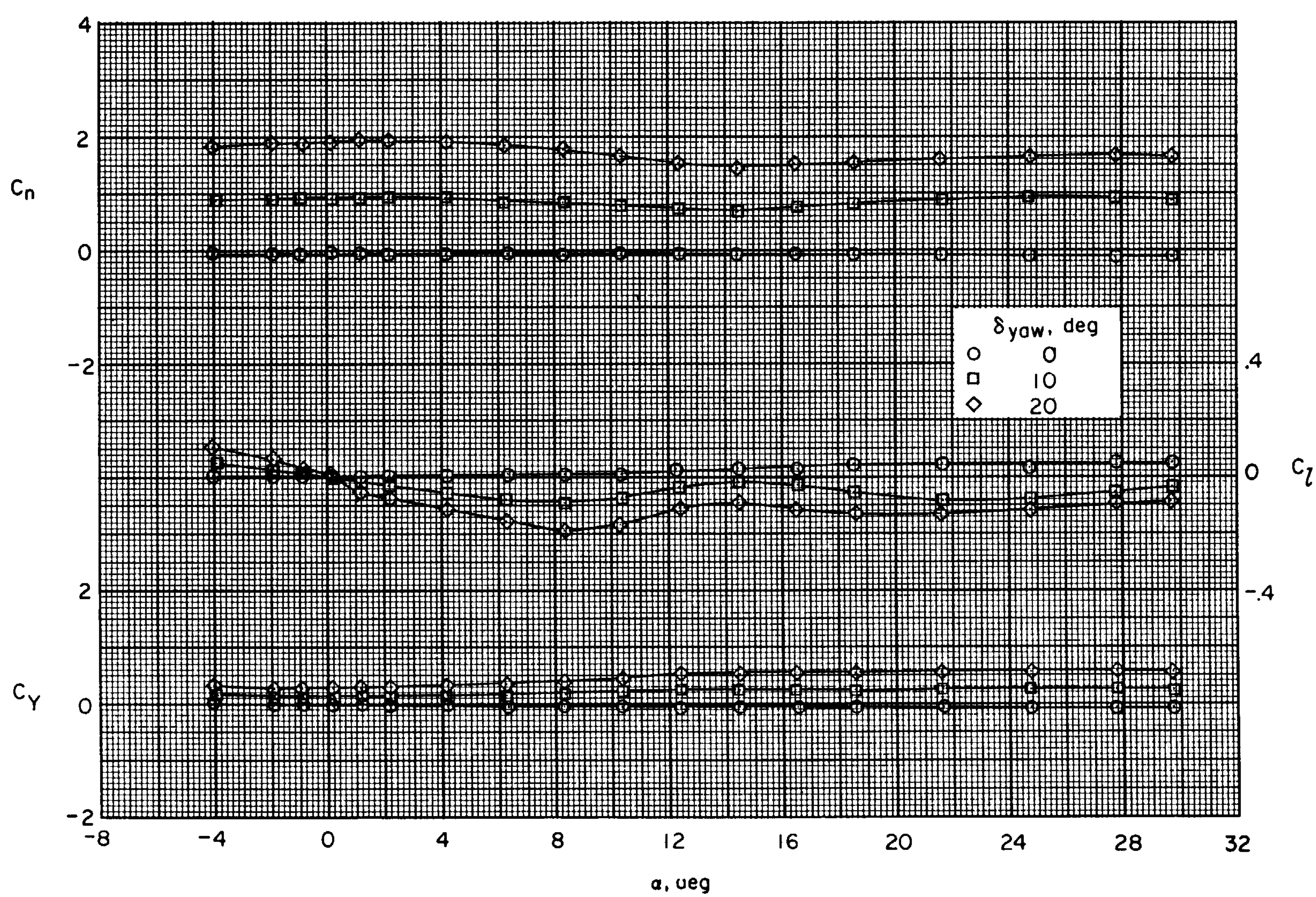
(c) M = 2.30.

Figure 9.- Continued.



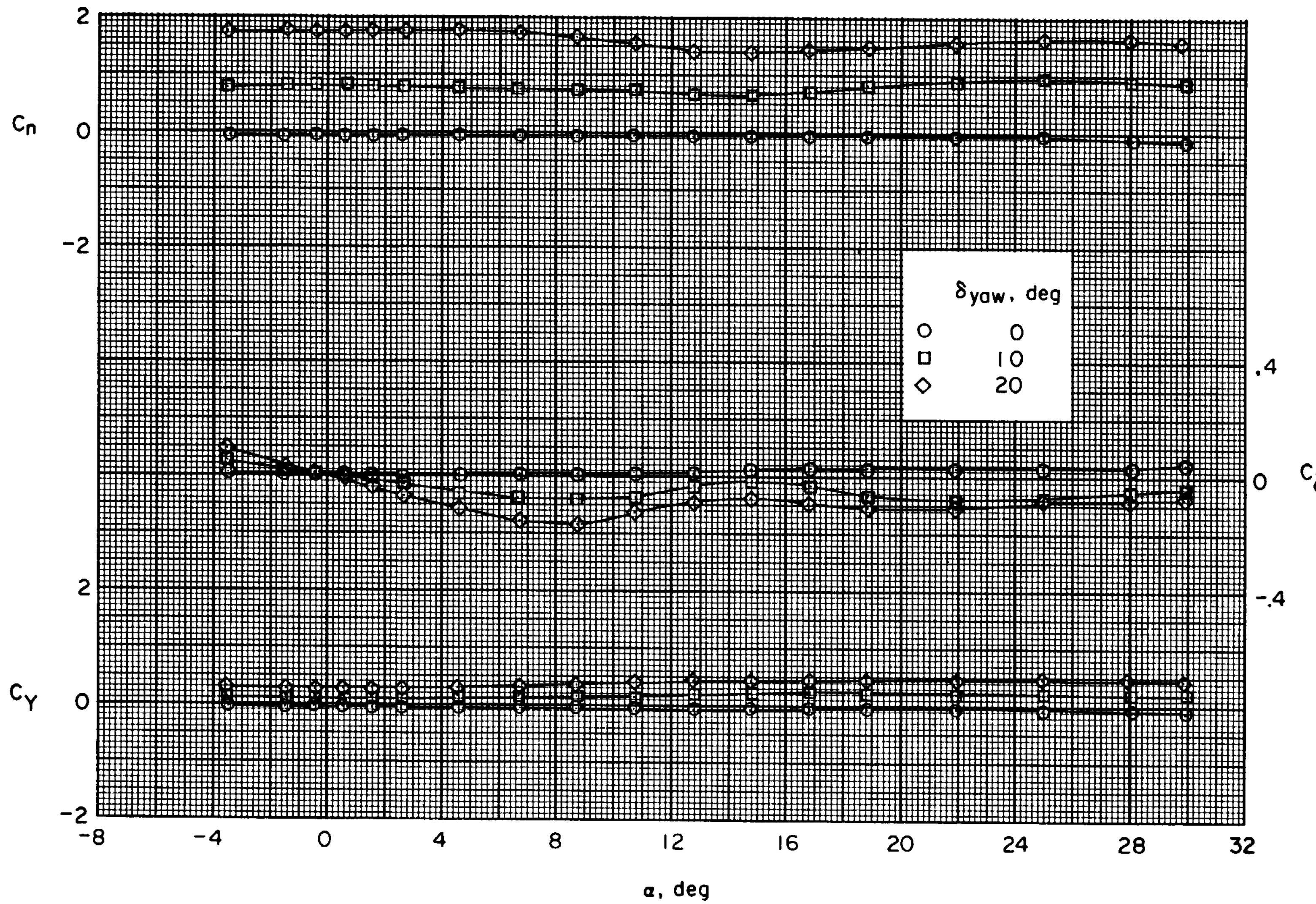
(d) M = 2.96.

Figure 9.- Continued.



(e) M = 3.95.

Figure 9.- Continued.



(f) M = 4.63.

Figure 9.- Concluded.

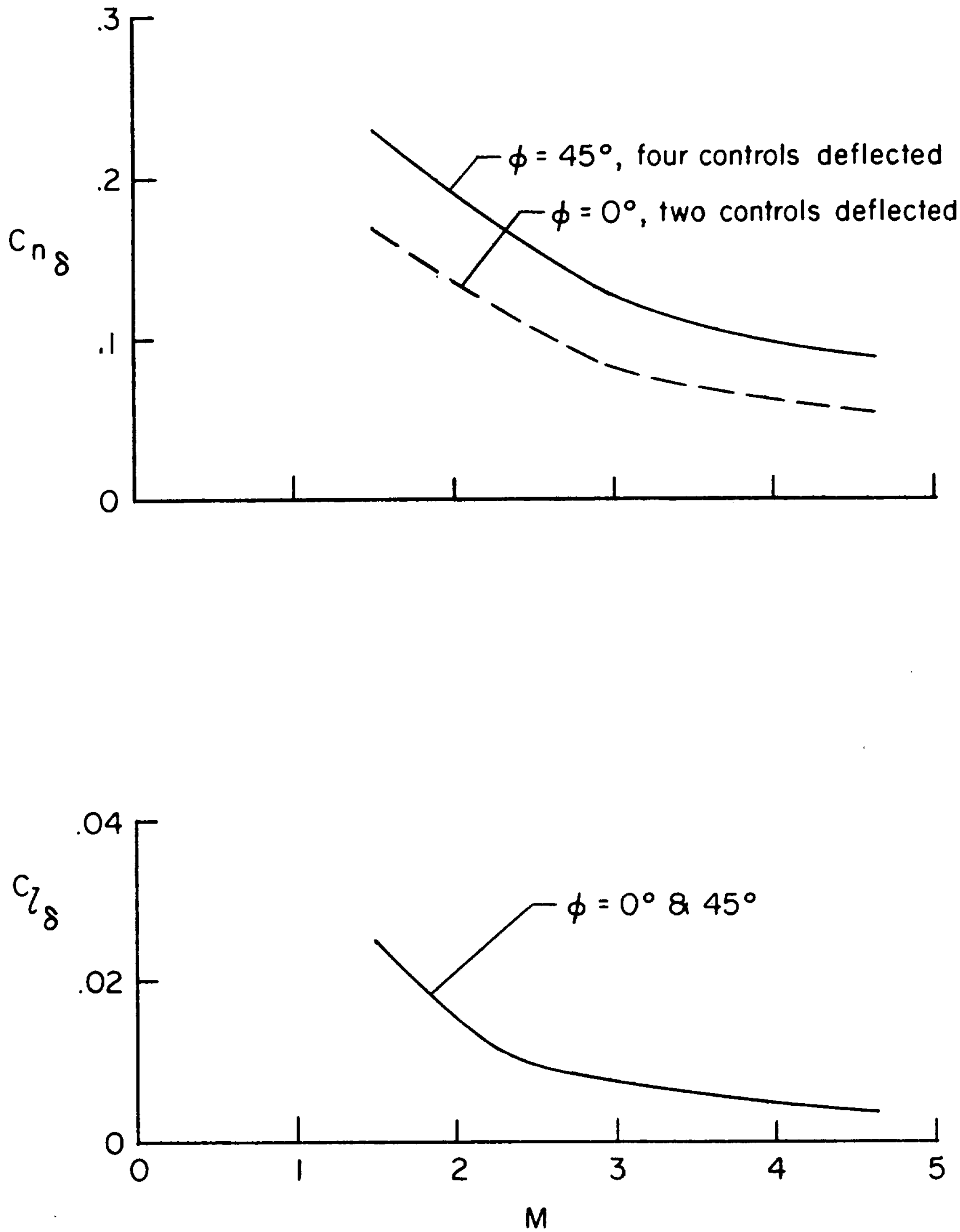


Figure 10.- Lateral-control summary. $\alpha = 0^{\circ}$.

NASA-Langley, 1967 L-5313